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Future
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HOW EYE TESTS WORK
The science behind prescribing your specs

ANCIENT GREECE
How did the Greeks change the world?

+ MARS MISSIONS
WHY DO WE SEND SO MANY SPACECRAFT TO THE RED PLANET?

BALEEN WHALES
The feeding habits of ocean giants explained

ANDROMEDA GALAXY
Get to know your cosmic neighbour

+ LEARN ABOUT ■ CHERNOBYL DOME ■ WALKIE-TALKIES ■ HAIR GEL ■ BALLROOM FLOORS

ISSUE 95

WELCOME

The magazine that feeds minds!

"Algae gives the coral its tropical, vibrant hue and turns the reef into a riot of submarine colour"

Secrets of the coral reef, page 26

Meet the team...

Charlie
Production Editor
The night sky might look serene, but the universe is a place of gigantic collisions. Head to page 38 to find out what will happen when Andromeda meets the Milky Way.

Dave
Editor-in-Chief
I enjoyed learning about the tech in development to make our cities smarter and greener. Maybe we'll all be eating locally sourced veg from the vertical farm next door soon.

Jack
Senior Staff Writer
The ancient Greeks created democracy, the Olympics, and even vending machines. Flick to page 72 and check out all their game-changing innovations.

James
Research Editor
When the great mind of Albert Einstein refers to a branch of science as 'spooky', you know it's worth your attention. Find out more about the mind-blowing quantum world on page 12.

Duncan
Senior Art Editor
I'll soon be ditching the train commute into the office and getting my own personal drone to fly me in to work. Find out how this will soon be possible on page 48.

Laurie
Assistant Designer
Take a dive into a great underwater world on page 26 as we uncover the secrets within some of the largest living structures found on the planet, coral reefs.

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I remember first studying the double-slit experiment at school, and learning that light behaves as both a particle and a wave. Up until then, physics made sense to me, but the concept of wave-particle duality was mind-boggling. That lesson was my introduction to the weird world of quantum mechanics.

The bizarre effects of quantum physics are being exploited to develop quantum computers, which will revolutionise how data is processed. A quantum computer can work on millions of calculations simultaneously, rather than making each calculation in sequence, one after the other, like a traditional computer. Find out more about the strange science of quantum mechanics and its applications on page 12.

Also this issue, we dive into the world's coral reefs, look to the future of smart cities, take a ride in a passenger drone, meet our galactic neighbour and take a tour of ancient Greece.

Enjoy the issue!

Jackie **Jackie Snowden**
Deputy Editor

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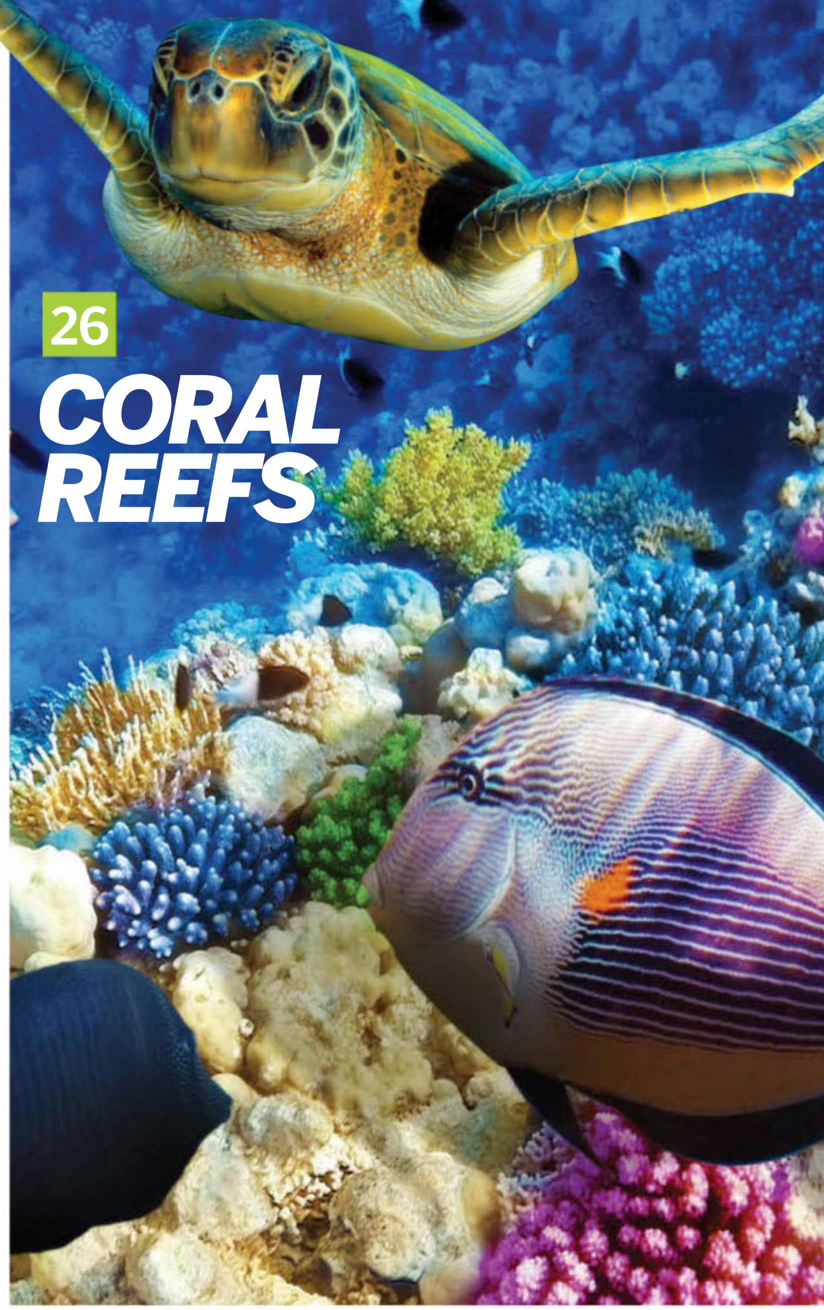

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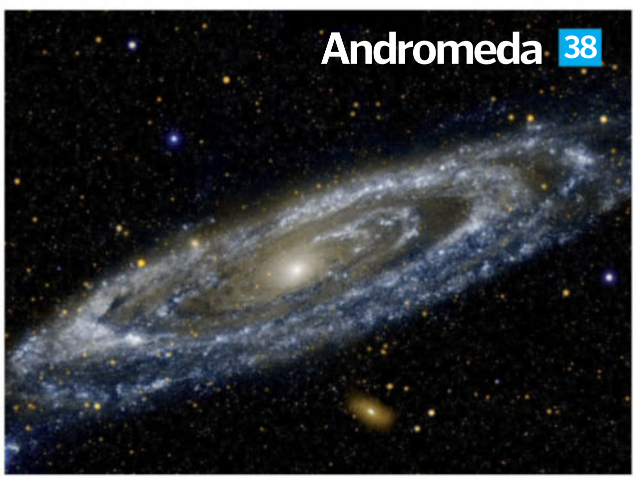

Andromeda 38

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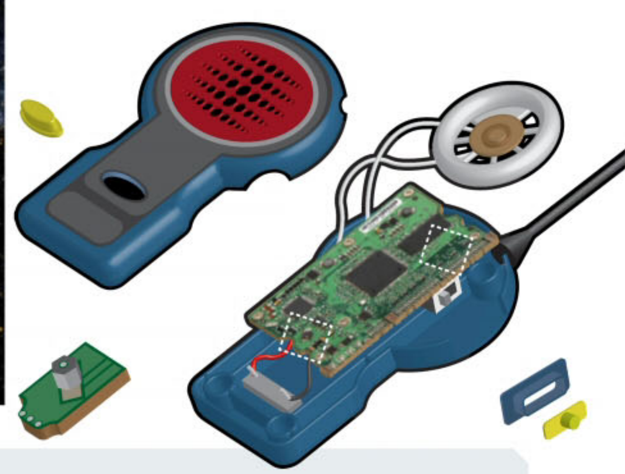


Meet the experts...

Ella Carter
This month marine biology expert Ella explains some of the most exciting developments in the study of coral reefs. She also investigates why birds build different types of nests on page 34.

Laura Mears
In our space feature, Laura takes us on a tour of one of our closest galaxies, Andromeda. Find out how we study our cosmic neighbour and what will happen when it collides with the Milky Way.

Jo Stass
In our latest Heroes Of... feature, Jo takes a look at the life of one of the most influential figures in medicine: Florence Nightingale. She also explains the science behind a trip to the opticians on page 25.

Laurie Winkless
In this issue's tech feature, Laurie looks to the future of cities. Could the urban skyline soon be filled with vertical farms and skyscrapers covered in solar panels? Find out on page 58.

Stephen Ashby
In this month's transport feature, tech fan Steve explores the gadgets of the personal travel revolution, from electric skateboards to your very own personal passenger drone.

REGULARS

Go to page 92 for great deals

Snow in the Sahara

Snow falls on the dunes of the North African desert for the first time in 38 years

The Sahara Desert is the largest hot desert on Earth, spanning some 9.2 million square kilometres. On 19 December 2016, snowflakes fell on Saharan sand. The rare event was recorded outside the town of Ain Sefra in Algeria, which is known as 'The Gateway to the Desert'. The snow may have only lasted for a day, but it is an extraordinary anomaly, despite temperatures in this region at this time of year typically falling to a few degrees above freezing.

The last time flakes fell on the sands was in the same location on 18 February 1979, when the area was hit with a snowstorm that lasted for 30 minutes. Rainfall is uncommon in the Sahara and only a few centimetres fall every year. This is the main reason why snow is such a rare occurrence, even when the climate grows cold, as water must first freeze for snow to form.

Although snow settling on the sand is atypical, it's a common sight on the Atlas Mountains, which border the northern edge of the desert. Algeria actually has several ski resorts that tourists flock to each year.

This image taken by NASA's Landsat 7 satellite shows the snowfall on 19 December 2016

More weird weather

Feeling foehn
On 22 January 1943, the temperature in the South Dakota town of Spearfish in the US soared upwards by 27 degrees Celsius in just two minutes. The temperature climbed rapidly from -20 to 7 degrees Celsius due to an intense foehn wind.

Tan down under
Marble Bar in western Australia is known for its sweltering temperatures, and in 1923 temperatures didn't dip below 37 degrees Celsius for 160 days. This world record was set between 31 October 1923 and 7 April 1924.

Incoming
Hailstones the size of softballs fell in Nebraska, US on 22 June 2003. Some residents opted to wear crash helmets to protect themselves as the huge stones smashed roofs and left deep craters in the ground.

Record rain
La Reunion Island in the Indian Ocean endured over six metres of rain over 15 days in January 1980, in one of the heaviest rainstorms of all time. This extreme weather was down to a tropical cyclone that left 7,000 people homeless.

Desert deluge
The Atacama Desert in South America is one of the driest places on Earth. On average, this desert records just 0.17 centimetres of rainfall a year, but in March 2015 almost 14 years worth of rain fell in a single day.

Over 1,500 passengers perished in the Atlantic Ocean as a lack of lifeboats proved fatal

NEW TITANIC SINKING THEORY EMERGES

The latest evidence suggests an on-board fire contributed to the famous tragedy

For over a century it was believed that the sinking of RMS Titanic was solely due to a fatal collision with an iceberg. Now, almost 105 years since the disaster, research has identified a potential new contributing factor to the sinking: a fire.

A renewed study on rare photographs taken by the ship's chief electrical engineers has shown that a section of the right-hand side of the hull was covered in nine-metre-long black marks. These are believed to be the traces of a fire that raged for weeks after coal in a fuel store was set alight during speed trials while the ship was still in Southampton, UK. White Star Line decided not to inform any passengers and the vessel sailed as the fire raged on. The blaze was eventually extinguished during the transatlantic crossing, but the damage had already been done and the ship's fate was sealed.

Experts claim the temperature of the fire peaked at 1,000 degrees Celsius, which weakened some of the steel in the ship's hull by up to 75 per cent. The black marks are also where the impact of the iceberg was at its greatest, so it's now speculated that the damage from the impact was augmented by the effects of the fire.

The blaze could also be the reason the Titanic was travelling so quickly through the iceberg fields. To put out the fire, the crew were shovelling the burning coal into the boilers, therefore speeding up the ship. Experts still believe the ship would have sunk even without the fire, but if the new theory is correct, the fire damage accelerated its plunge below the waves.

Raising Titanic

From packing the wreck full of ping-pong balls to bringing it to the surface with magnets, many suggestions have been made as to how to raise the Titanic. The wreck site was first located in 1985, and in 1998 a 20-ton section of the hull was raised. Since then, various submersibles have investigated the wreck, successfully creating a 3D map of the site. If more attempts are to be made, time is a factor as a combination of bacteria and ocean currents are gradually eroding the remains of the doomed ship.

The official inquiry into the disaster described the reason behind the sinking as 'an act of God'

NEWS BY NUMBERS

£7 billion

The estimated cost of the John Lewis 2016 Christmas advert

400

Worldwide number of earthquake tremors detected by app MyShake since February 2016

20

Percentage of the world's population that celebrate Chinese New Year

60,000

Tons of CO_2 to be saved every year by a new Indian industrial plant

NASA scientists believe that ice will be an optimal material to shield against harmful galactic cosmic rays

Mars colonists could live in 'igloos'

NASA has revealed a new approach to potential colonies on Mars: ice houses

If humans ever set foot on Mars, they will need adequate shelter to guard against radiation and extreme temperatures. A new study by NASA has proposed that one of the best materials to use would be ice. Known as the Martian Ice Dome, a lightweight shell of frozen water will be constructed by robots, and when the colonists need to return to Earth, it could potentially be converted into rocket fuel or used as a storage tank. The Ice Dome will enable astronauts to stay for much longer then they did on the Apollo missions to the Moon, and could one day provide a temporary shelter for permanent colonies on the planet.

One patient has already claimed that the technology enabled him to recognise large letters

Bionic eyes could help cure blindness

A new implant could help those who are partially sighted see again

In a trial funded by the NHS, ten patients with retinitis pigmentosa will be fitted with a bionic eye that aims to help them regain their sight. A patient-worn camera captures a scene and then uses a video processing unit worn on the hip to send the data wirelessly to a retinal implant. This triggers small pulses of electricity that bypass damaged photoreceptors and instead stimulate the remaining cells in the retina, allowing the brain to perceive patterns of light.

'New' organ discovered in human body

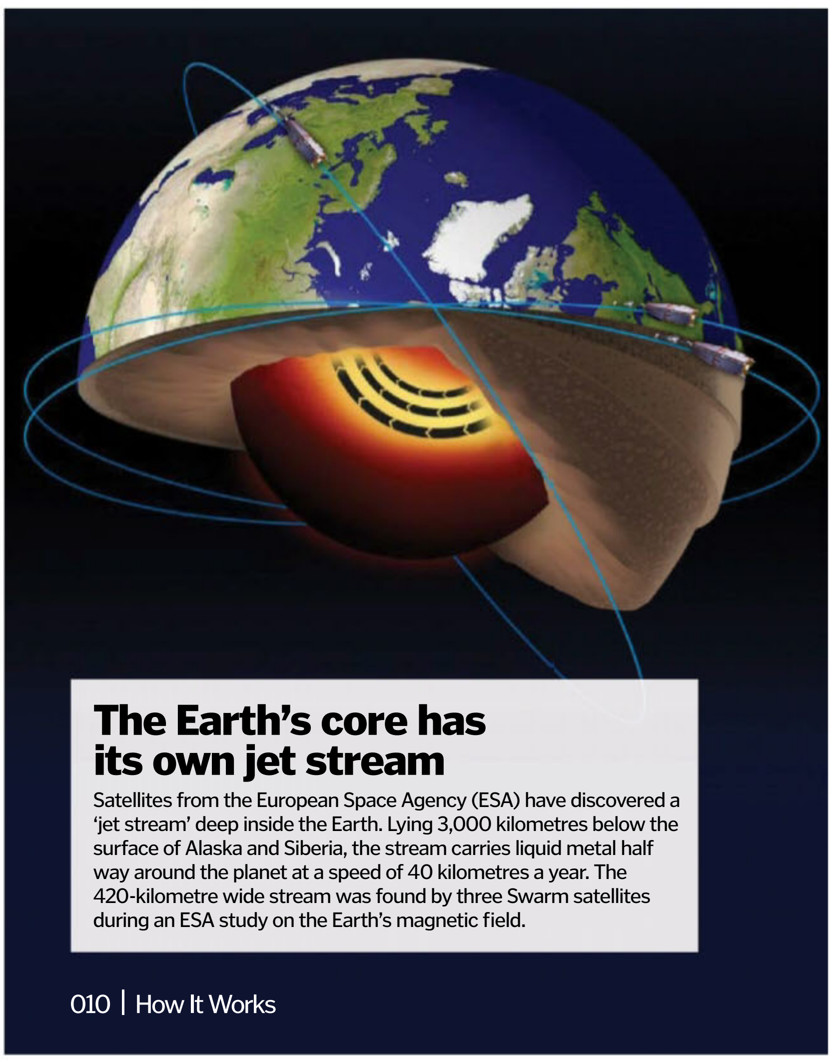
This recent finding could improve our understanding of abdominal diseases

The human body has a 'new' organ: the mesentery. Part of the digestive system, it was long thought to be several different structures, but recent research has shown it to be one of the human body's now 79 organs. Microscopy work undertaken at the University Hospital Limerick found that the mesentery is a double fold of membrane that helps hold the digestive system together. Despite the discovery, researchers are still unsure on the full extent of the organ's function, but extra study may reveal the answer.

10 COOL THINGS WE LEARNED THIS MONTH

Speedy gene editing is being used in humans for the first time

CRISPR is a ground-breaking form of gene editing, and there are hopes that it could be used to help fight cancer. The procedure is being trialled in both China and the US, and aims to alter immune cells so that they are able to recognise cancer. A method is also being devised to shut off the CRISPR system once it's done its job so it shouldn't make any extra, unwanted genetic alterations.



The Earth's core has its own jet stream

Satellites from the European Space Agency (ESA) have discovered a 'jet stream' deep inside the Earth. Lying 3,000 kilometres below the surface of Alaska and Siberia, the stream carries liquid metal half way around the planet at a speed of 40 kilometres a year. The 420-kilometre wide stream was found by three Swarm satellites during an ESA study on the Earth's magnetic field.

Salamanders go the extra mile to find a mate

Small-mouthed salamanders travel almost nine kilometres on average in order to reproduce, risking death and dehydration. Scientists tested the amphibian's endurance on small treadmills and found that small-mouthed salamanders were able to last four-times longer than those of a closely related group, which use cloning to reproduce. Some managed to walk on the treadmill for two hours, an impressive show of stamina similar to a human jogging 120 kilometres.

Next-gen air-con could beam heat into space

Radioactive cooling is an extremely efficient version of air conditioning. By using a thermal emitter, physicists radiated heat out from Earth and into space. The emitter was placed in a vacuum chamber and directed at a clear sky. After 30 minutes, the emitter temperature fell by 40 degrees Celsius. This method could be used in the future to help chill medicines.

Monkeys would be able to talk if their brain structure was different

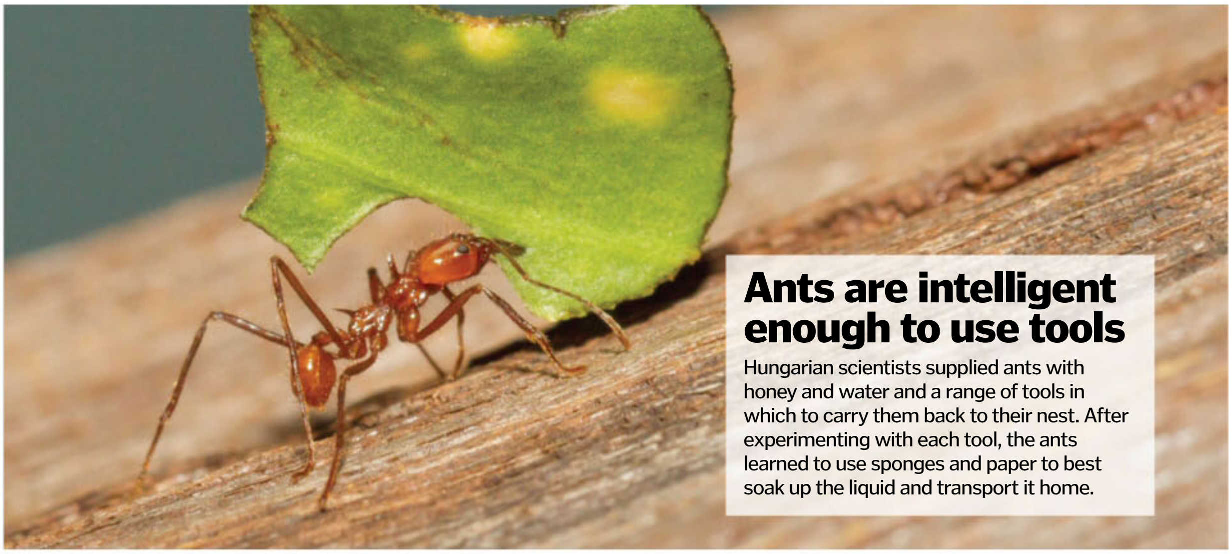
Research has found that macaques have vocal tracts capable of speech. X-rays of a macaque eating and yawning showed they have the anatomy to make vowel sounds but lack the brainpower to do so.

Moon colonists could live in lava tubes

Below the Moon's surface lie huge caverns formed by dried up molten rock from ancient volcanoes. Up to five kilometres in diameter, these subterranean cavities could be used to house future colonies. The tubes were spotted after small variations in the Moon's gravitational pull were noticed, and if colonised, could protect potential settlers from radiation, harsh temperatures and meteor strikes.

The brain actively filters out background noise

Known as the 'cocktail party effect', the brain uses selective hearing to concentrate on one conversation. Auditory tests using electrodes measured the difference in brain activity when exposed to incomprehensible speech followed by clear conversation.



Ants are intelligent enough to use tools

Hungarian scientists supplied ants with honey and water and a range of tools in which to carry them back to their nest. After experimenting with each tool, the ants learned to use sponges and paper to best soak up the liquid and transport it home.

Time spent outside is good for your eyes

Recent reports suggest rising rates of nearsightedness in children are down to too much time being spent indoors. By concentrating on brightly lit close-up objects like ebooks and smartphones, children's eyes don't have the opportunity to focus on distant objects, possibly making the onset of myopia more rapid. Experts believe this can be effectively combated by spending more time outdoors.

Killifish have adapted to survive toxic pollution levels

A species of fish has managed to withstand water contaminated with industrial waste. Atlantic killifish cells mutated until the correct genetic combination effectively protected cells from the toxins. The fish subsequently became up to 8,000 times more resistant to the harmful substances. The killifish's ability to quickly change its genes was the key to so many being able to survive.

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QUANTUM POWER

THE FUTURE OF COMPUTING AND HOW IT WILL CHANGE YOUR WORLD

MEDICAL RESEARCH

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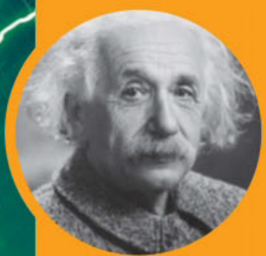
The pioneers of quantum mechanics

Introducing the people who dared to think the unthinkable, laying the foundations of quantum technology



Albert Einstein 1905
Einstein explained the photoelectric effect by suggesting that light took the form of discrete bundles called photons. This seemed at odds with light's wave nature.

Louis de Broglie 1923
French physicist Louis de Broglie expanded on previous discoveries by proposing that all tiny particles can behave as waves, and vice versa.

Erwin Schrödinger 1926
Austrian physicist Erwin Schrödinger's paper describing the motion of an electron as a wave function was a defining moment in quantum mechanics.

Werner Heisenberg 1925-1927
Alongside Niels Bohr, Werner Heisenberg suggested that subatomic particles only adopt a particular state when observed.

Alexander Holevo 1973
Russian mathematician Alexander Holevo was one of several researchers to lay down the theoretical foundations of quantum mechanics.

It might be a term that trips off the tongue, and it may suggest a field of study dominated by the scientific elite, but quantum mechanics – or quantum physics if you prefer – is largely a mystery to the layperson. Surprisingly, therefore, it couldn't be much simpler to sum it up, even though understanding it is considerably more difficult.

Quantum mechanics is concerned with the behaviour of atoms, photons and the various subatomic particles, and it contrasts with classical physics, which describes the behaviour of everyday objects that are large enough to see.

The difference between classical physics and quantum mechanics is absolutely staggering. The objects that we see in the world around us behave in a way that seems intuitive, but once we start to consider very small objects, intuition and common sense have to be abandoned.

Instead, when we consider them individually, atoms, electrons and photons behave in a way that most people would be inclined to describe as impossible. That perception of impossibility isn't a naive view either. Even the eminent Nobel Prize-winning physicist Niels Bohr is on record as saying "If anybody says he can think about quantum theory without getting giddy, it merely shows that he hasn't understood the first thing about it."

We'll look at some of these concepts in more detail in the boxout below, but, having made such an astonishing claim, it's surely only appropriate to provide a couple of examples of apparently impossible quantum behaviour.

Perhaps one of the most bizarre things that can happen in the subatomic realm is that objects such as electrons or photons can be in two places at the same time or in two different states at once – a so-called state of superposition.

> "The difference between classical physics and quantum mechanics is absolutely staggering"

Quantum concepts

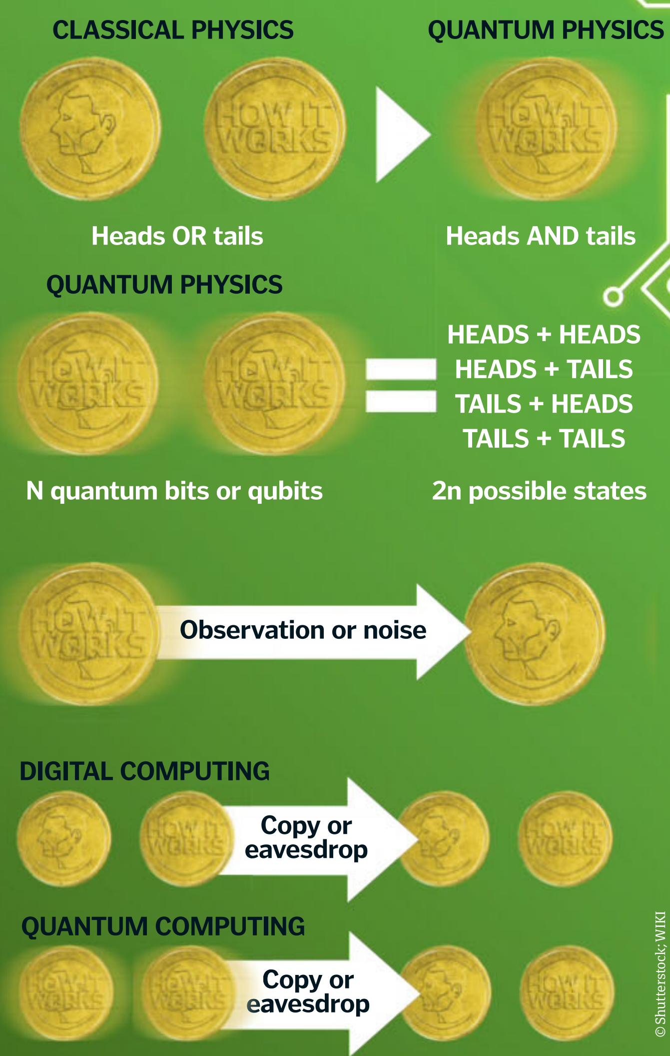
Examining the bizarre quantum effects that underpin quantum technology

Superposition
A particle in superposition is in two states at once, so it could represent both a binary 0 and 1. Think of a coin: if it's spinning you can see heads and tails simultaneously.

Entanglement
Two entangled particles are strangely linked, so the fate of one affects the other. If you observe one particle this will cause its superposition to be lost, and the same will happen to its entangled twin.

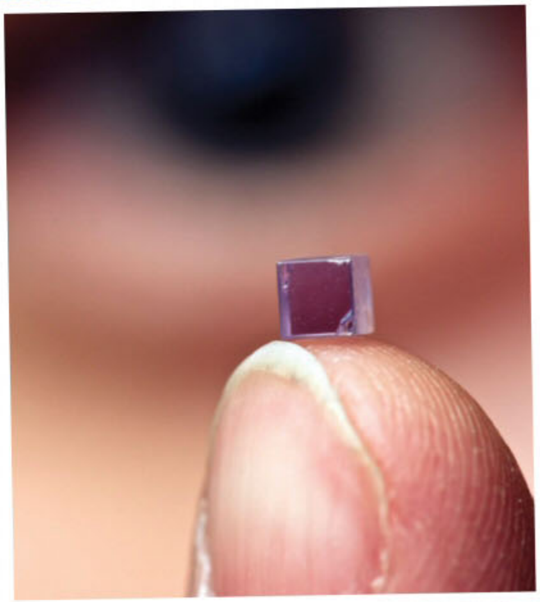
Observation
Observing a particle in superposition causes it to adopt a single state. Any interaction with the environment does the same. The more entangled the particles, the harder it is to maintain superposition.

No cloning
Making a copy of a particle in superposition also causes the superposition to be lost. This makes designing a quantum computer tricky, but, in quantum communications, it alerts the sender to the presence of an eavesdropper.

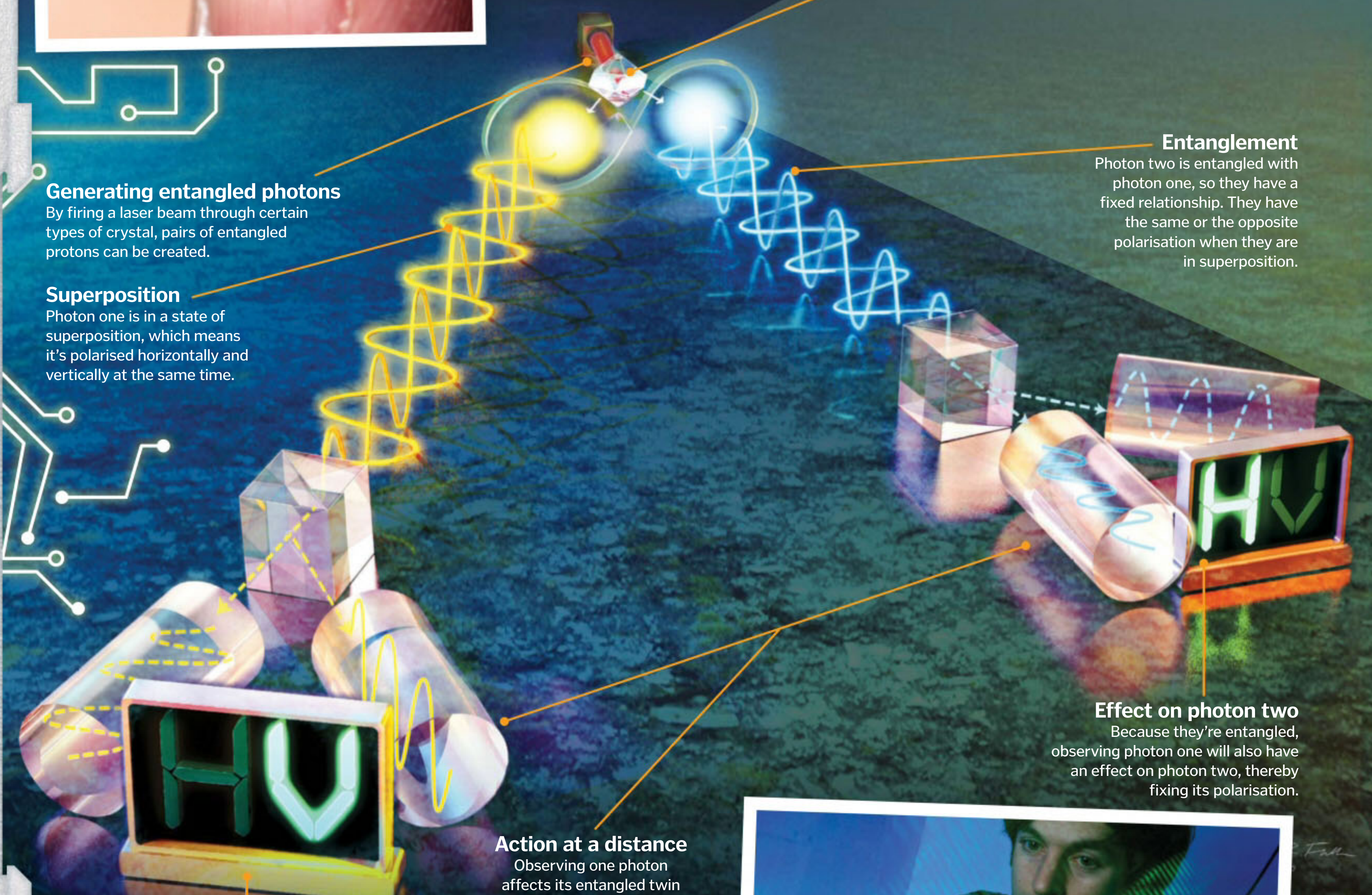


Understanding quantum entanglement

Experiments have confirmed a quantum effect that Einstein called "spooky"



Crystals doped with the rare element neodymium could potentially store quantum memories



Splitting the beam
In this experiment a beam-splitter is used so that the two photons are dispatched to different destinations.

Generating entangled photons
By firing a laser beam through certain types of crystal, pairs of entangled protons can be created.

Entanglement
Photon two is entangled with photon one, so they have a fixed relationship. They have the same or the opposite polarisation when they are in superposition.

Superposition
Photon one is in a state of superposition, which means it's polarised horizontally and vertically at the same time.

Effect on photon two
Because they're entangled, observing photon one will also have an effect on photon two, thereby fixing its polarisation.

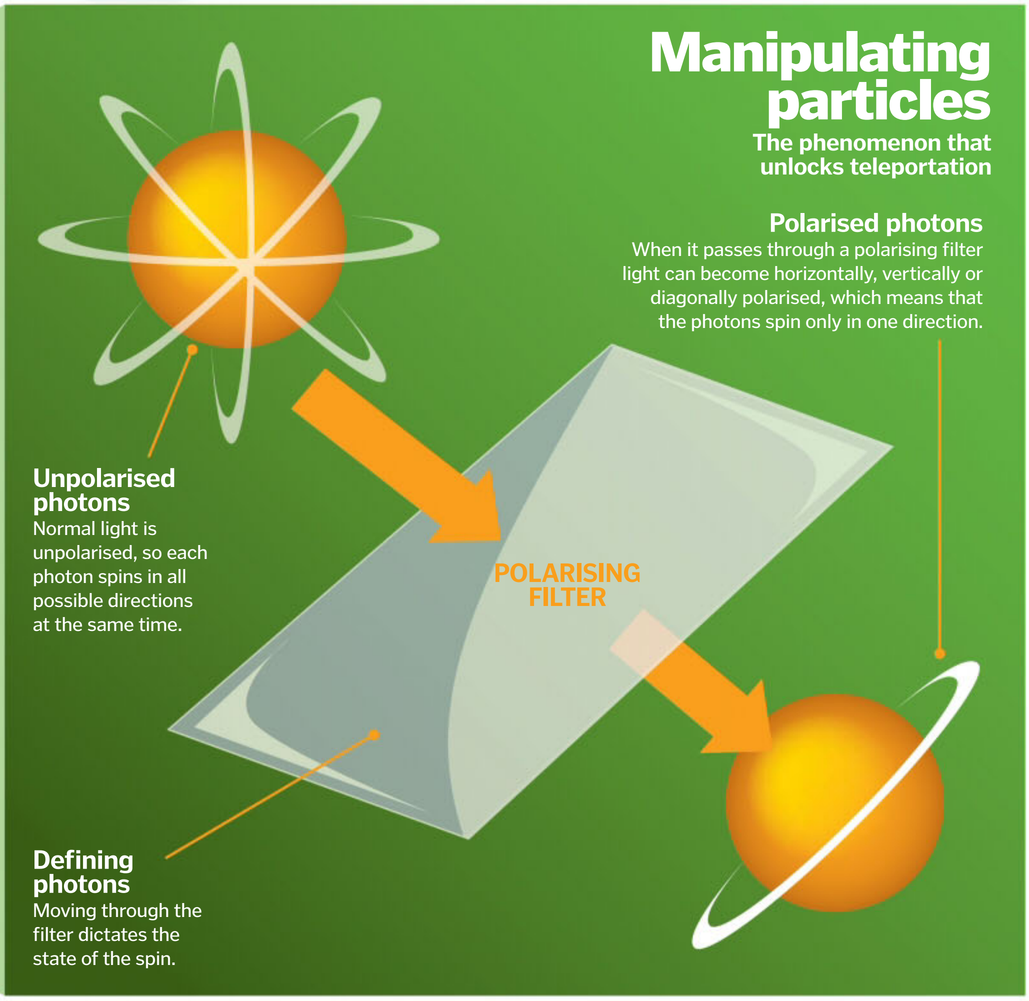
Action at a distance
Observing one photon affects its entangled twin instantaneously, no matter how far apart the two photons are.

Observing photon one
When photon one is observed, superposition is lost and it will appear to be either horizontally (H) or vertically (V) polarised.

A scientist at the University of Geneva in Switzerland uses a laser to create entangled photons in researching quantum memory

Manipulating particles

The phenomenon that unlocks teleportation

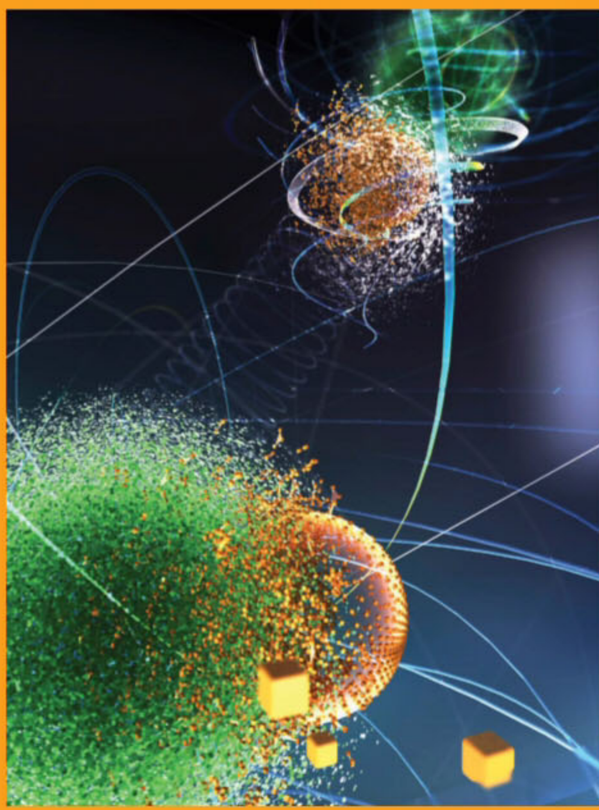


Quantum teleportation

We might be a considerable way from teleporting people, but single atoms and photons have already been teleported thanks to the use of quantum techniques.

The process involves creating two entangled particles at place A and then sending one of them to place B. Now, using clever techniques that also involve introducing a third particle that interacts with particle A, entanglement causes the particle at B to become an exact copy of the third particle. In reality, the actual particle hasn't moved, but the result is the same, so, effectively, the third particle has teleported to B's location instantly.

As with all things quantum, in practice this is incredibly difficult, and scientists are in a race to beat distance records. While the current record is 143 kilometres using a laser beam in September 2016, researchers in Calgary, Canada, and Shanghai, China, demonstrated quantum teleportation using a more practical fibre optic network to teleport photons across their respective cities.


Atoms and photons can now be teleported over ever-increasing distances

You'll never be able to observe this odd state of affairs because, as soon as you try to do so, that object will appear to be in just the one place or one state. However, scientists have conducted cunningly-devised experiments that have confirmed that this peculiar behaviour really does happen, despite indications to the contrary whenever we try to observe it.

Another strange effect is called quantum mechanical tunnelling, and it refers to the fact that a tiny object is capable of passing straight through a solid barrier without damaging it. So, for example, if you fire an electron at a sheet of gold foil, there's a possibility that it could appear at the other side with the foil still intact.

The fact that particles can be in two places at once, and that they can pass through solid objects, both stem from the dual nature of tiny objects. At one time light was thought of as a wave, but later it was discovered that it could be described as a stream of particles called photons. Conversely, electrons were once considered as miniature particles that orbited an atom's nucleus like planets orbiting a sun, but subsequently it was discovered that they could be described as wave functions.

In reality, electrons and photons each have the properties of both particles and waves, or, in other words, both concepts are correct. So, that strange phenomenon in which an electron can be in two places at once is a consequence of the wave nature of electrons.

Instead of that now outdated view of orbiting electrons, wave theory concerns a so-called probability function. In other words, it describes the probability of the electron being at any particular point in space and, until the electron is observed, its position can be thought of as all points in space, albeit with some places being more likely than others.

What we've seen so far has been known since the early 20th century, and it's strange enough. So any hope of ordinary people understanding the more recent developments in quantum theory is a forlorn one. However, to illustrate just how bizarre current thinking can be, let's think briefly about the multiverse theory, although even this dates back to the 1960s and 1970s.

You'll recall that observing a particle in a state of superposition causes its previously unknown position or state to become fixed. In the science-fiction-sounding multiverse theory, as soon as that observation takes place, the universe splits into two or more parallel universes, with that

"Scientists have now taken their first steps in quantum teleportation"

particle being in a different location or state in each version of reality. What's more, with vast numbers of these splits taking place each second, that soon gives us an unimaginable number of parallel universes. This theory has gained additional credence recently as scientists have started to consider quantum computers. As we'll see later, compared to today's devices, if large-scale quantum computers ever become a reality, the performance they will offer will be absolutely astonishing.

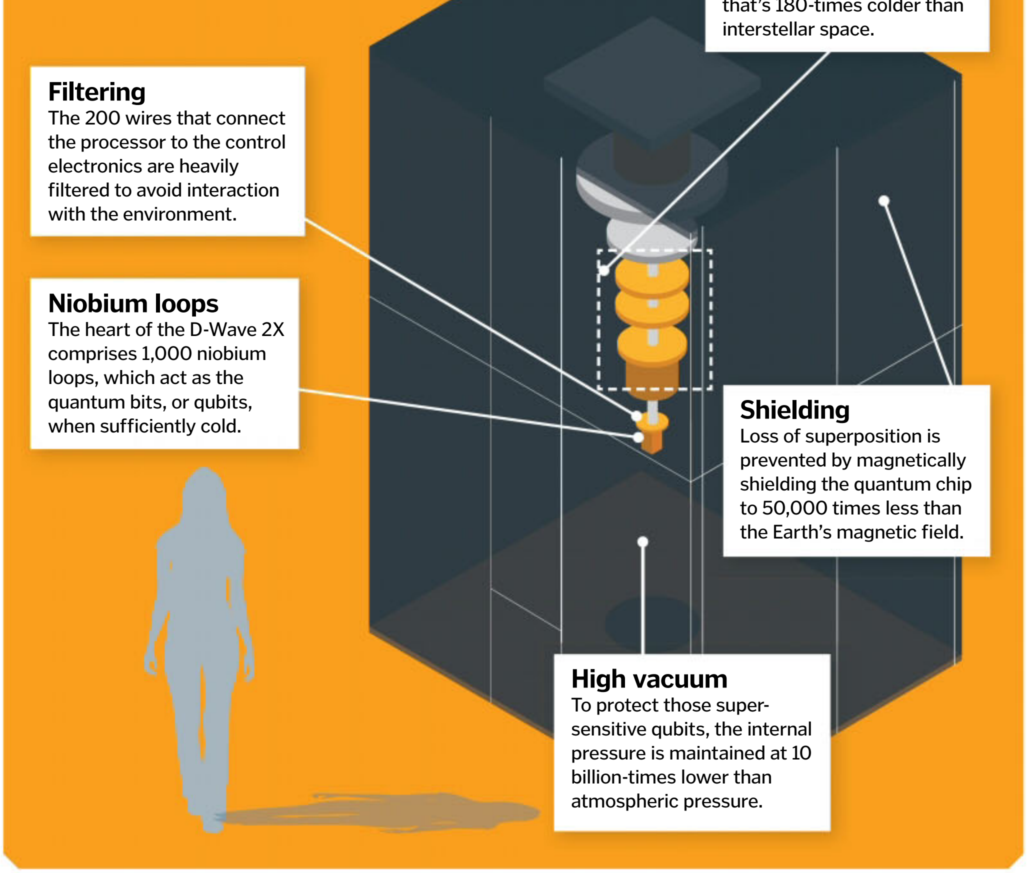
This has led some scientists to suggest that there isn't enough material in the observable universe to carry out such a phenomenal number of computations. In the multiverse theory, however, that work is effectively farmed out into all of those parallel universes.

Given its very theoretical foundations, some people might be excused for thinking that quantum mechanics is an entertaining curiosity for scientists, but of absolutely no practical use. But experience has proven that most theoretical studies impact the real world eventually, and there's every indication that the same is true of studies in the quantum realm. Quantum mechanics has already given birth to many technological breakthroughs, and there are tantalising glimpses of what may lie ahead.

For a start, today's solid-state devices, which impact so much of 21st century life, depend on quantum effects. Most importantly, perhaps, is the transistor, which is the fundamental building block of computers, smartphones and pretty much all electronic devices. Another important solid-state device is the LED and the

The D-Wave 2X quantum computer

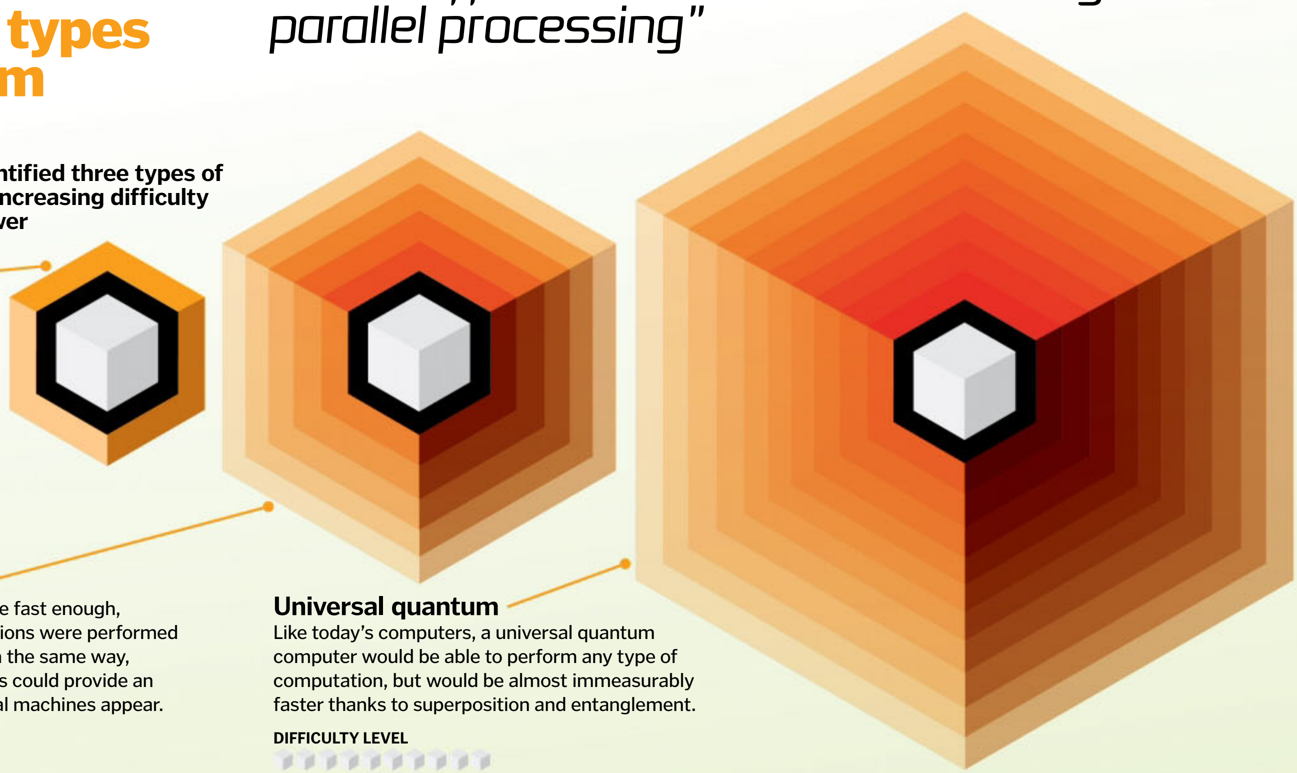
The secrets of one Canadian company's latest and greatest creation



"A universal quantum computer would offer the ultimate in massively parallel processing"

The three types of quantum computer

IBM Research have identified three types of quantum computer of increasing difficulty but also increasing power



Quantum annealer

Today's only commercial quantum computer is a quantum annealer. This is a specialised architecture that is designed for a whole range of applications that are described as optimisation tasks.

DIFFICULTY LEVEL

Analogue quantum

Before digital computers were fast enough, high-speed scientific calculations were performed using analogue computers. In the same way, quantum analogue computers could provide an interim solution until universal machines appear.

DIFFICULTY LEVEL

Universal quantum

Like today's computers, a universal quantum computer would be able to perform any type of computation, but would be almost immeasurably faster thanks to superposition and entanglement.

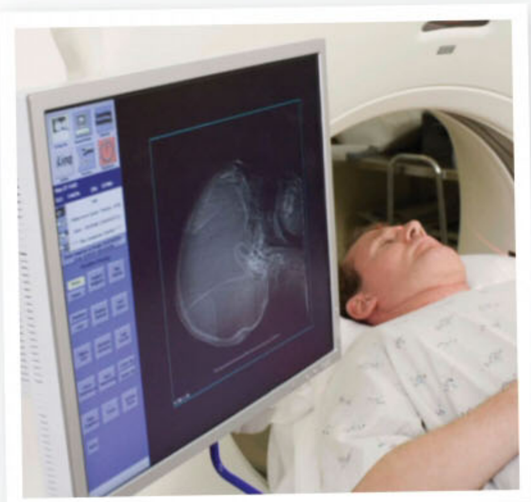
DIFFICULTY LEVEL

closely related solid-state laser. The former is now revolutionising lighting by bringing hitherto unprecedented levels of energy efficiency, while the latter is key to the fibre optic cables that span the globe empowering the internet, and is also a vital component in CD and DVD drives.

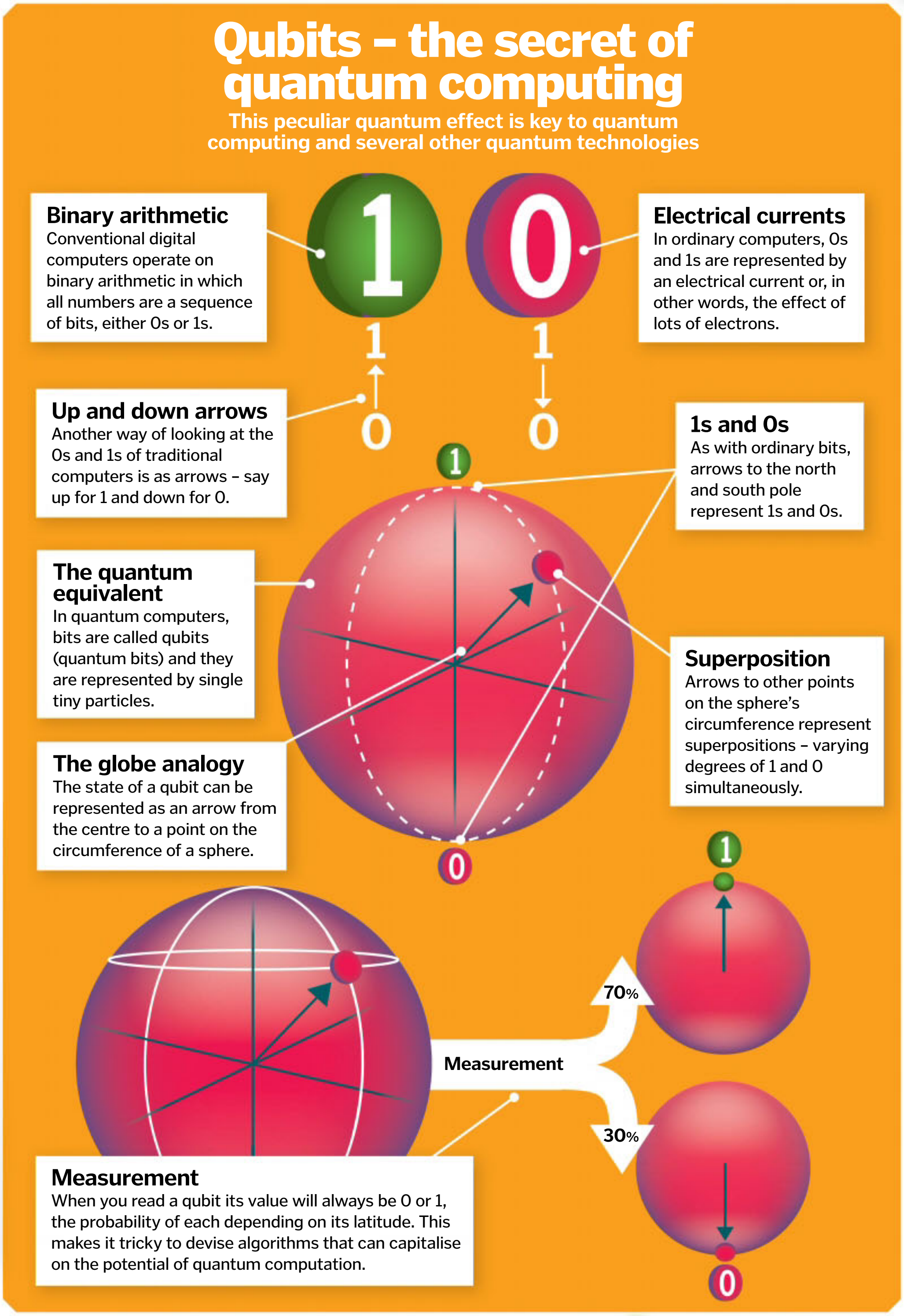
Atomic clocks are also reliant on quantum mechanics, and these instruments provide the precision timing needed for the operation of GPS systems on which sat navs and smartphone navigation apps rely. Quantum mechanics also underlies the principles of magnetic resonance imaging (MRI) machines, which allow physicians to see inside the body.

Little was said about their quantum heritage when these various technologies were developed, but we're now starting to hear about several new technologies that are much more up front about their quantum roots. What's more, these up-and-coming applications of quantum mechanics are absolutely mind-blowing.

Thought that *Star Trek* style teleportation was the result of an over-active imagination? Think again – scientists have now taken their first steps in quantum teleportation. What about a code that is totally unbreakable? Experience tells us that however sophisticated a code, all it takes is a sufficiently powerful computer and encrypted



MRI scanners work using the principles of quantum mechanics



Quantum computers by numbers

100 million times
How much faster the D-Wave 2X is compared to an ordinary computer

2^1,000
Number of solutions the current D-Wave 2X quantum computer can search simultaneously

1,000
The greatest number of entangled qubits achieved

18.4 billion billion
How many calculations a universal 64-qubit quantum computer could do simultaneously

2^16
How many simultaneous searches the first 16-qubit D-Wave quantum computer could perform in 2007

100,000
Number of qubits needed for a practical universal quantum computer

messages can be accessed. Not so with quantum cryptography. This isn't a code that's so fiendishly difficult that it would take all the computers on the planet years to crack. This is a method of encryption that, according to the laws of quantum mechanics, is totally secure, however much computing power you throw at it. And then we have quantum computers and the world of opportunities it opens up.

For now, though, let's just say that one company is already selling a rather specialised quantum computer, and research continues into a quantum equivalent of today's PCs, a universal quantum computer. If these ever come to fruition, they won't just be incrementally faster than their predecessors, which have doubled in speed every couple of years or so. Instead, a truly universal quantum computer holds the promise of almost unlimited performance thanks to that strange quantum effect of superposition, coupled with the equally strange quantum effect of entanglement.

By being in millions upon billions of states at the same time, a universal quantum computer would offer the ultimate in massively parallel processing, in which multiple operations are carried out simultaneously.

It is widely acknowledged that last century was the era of electronics. Within a period of just 52 years the very first electronic device, the vacuum tube or valve, was invented, and this was superseded first by the transistor and then by the integrated circuit. It only took another 13 years for the first microprocessor to be released.

Renowned quantum physicist Professor Rainer Blatt has described the technological developments of the last century as the first quantum revolution, and with some justification. After all, many of the developments that underpin today's society resulted from an understanding of quantum mechanics and, in particular, wave-particle duality. Professor Blatt suggests that humanity now stands at the dawn of a second quantum revolution that will be empowered by the weird quantum effect of entanglement.

According to Professor Blatt, "In the early 1960s, the laser was still seen as a solution to an unknown problem, and today, just over 50 years later, lasers have become an indispensable part of our lives – I expect quantum technologies to develop along similar lines."

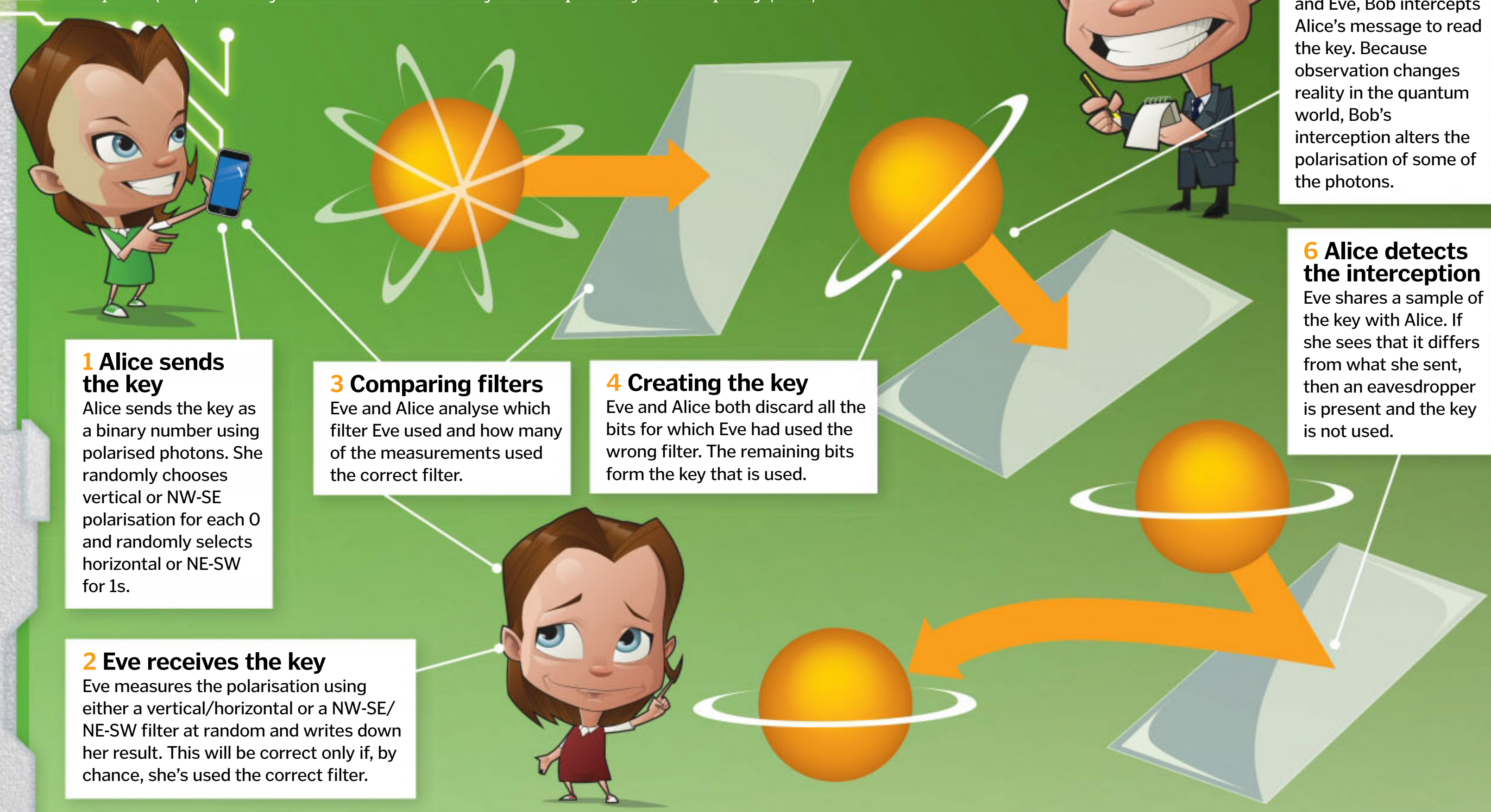
"We now stand at the dawn of a second quantum revolution"

Quantum computing has a wide range of applications, from improving air-traffic control systems to creating better speech recognition software

Quantum cryptography

How to send an encrypted message that is 100 per cent secure

Any message encrypted with a key as long as the message is unbreakable. The purpose of quantum cryptography is to transmit a key from the sender (Alice) to the intended recipient (Eve) in a way that alerts them to any interception by a third party (Bob).



1 Alice sends the key
Alice sends the key as a binary number using polarised photons. She randomly chooses vertical or NW-SE polarisation for each 0 and randomly selects horizontal or NE-SW for 1s.

2 Eve receives the key
Eve measures the polarisation using either a vertical/horizontal or a NW-SE/NE-SW filter at random and writes down her result. This will be correct only if, by chance, she's used the correct filter.

3 Comparing filters
Eve and Alice analyse which filter Eve used and how many of the measurements used the correct filter.

4 Creating the key
Eve and Alice both discard all the bits for which Eve had used the wrong filter. The remaining bits form the key that is used.

5 Bob intercepts the key
Unbeknown to Alice and Eve, Bob intercepts Alice's message to read the key. Because observation changes reality in the quantum world, Bob's interception alters the polarisation of some of the photons.

6 Alice detects the interception
Eve shares a sample of the key with Alice. If she sees that it differs from what she sent, then an eavesdropper is present and the key is not used.

Applying quantum mechanics

In the future there may be numerous ways to use this rapidly growing technology

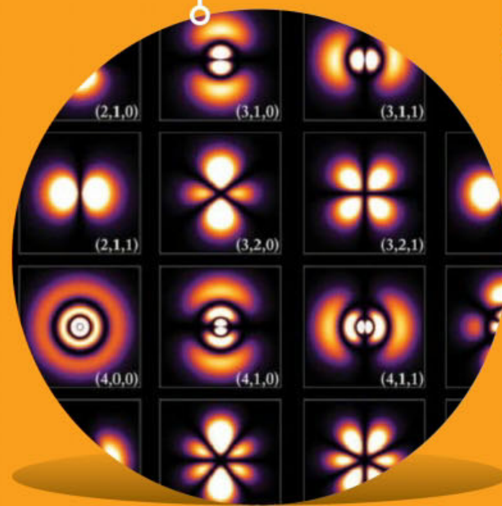


Image searching

Humans are easily able to detect familiar objects such as trees, lakes and cats when they look at a photograph. Teaching computers to do likewise is a really difficult programming task because it's so hard to define the essence of 'cat-ness', for example. But machine learning tasks like this are natural applications for quantum computers. Google has already invested considerable research effort into image analysis to make online picture searching more efficient. This was demonstrated by teaching a quantum computer to recognise cars in photos, a task it was then able to do much quicker than an ordinary computer could ever achieve.

Quantum simulation

It might seem like a circular argument but, just as an understanding of quantum mechanics has now given us quantum computers, scientists are now hoping that those same quantum computers will help them to better understand quantum systems by simulating them. Today's computers are able to carry out simulations of quantum effects but, such is the complexity of quantum systems, they are incredibly slow. It perhaps comes as no surprise, then, that computers that are based on the strange world of quantum mechanics are much more capable of simulating quantum systems and, thereby, help scientists to gain new insights.

Astronomy

Given that NASA jointly owns one of the world's first quantum computers, it's hardly surprising that astronomy will probably be one of the main beneficiaries of this new model of computation. The space agency has its sights set on several ways that quantum computing can assist in the exploration of space, but many of them can be summed up as searching through huge amounts of data for the proverbial needle in the haystack. A classic example is the search for habitable exoplanets; Earth-like planets in orbit at the ideal distance from faraway stars, that might just be capable of hosting life.

Radiotherapy optimisation

According to D-Wave Systems, their D-Wave 2X computer, working with a conventional computer, will help to optimise radiotherapy. This treatment aims to target a tumour while minimising harmful exposure to the rest of the body, with several beams intersecting at the tumour. Its optimisation involves juggling thousands of variables. To achieve it, simulations would be carried out on a huge number of possibilities using a conventional computer, while a quantum annealing computer would determine the most probable scenarios for simulation.

"Encrypted messages would be an open book for a general-purpose quantum computer"

Code breaking

A universal quantum computer would be able to factor large numbers with ease, a phenomenally time-consuming job for conventional computers. Today's ciphers rely on the fact that factoring is difficult, but encrypted messages would be an open book once general-purpose quantum computers become reality. This might be useful to the military and police forces – for example, in the fight against terror and organised crime – but it would also be a boost to cyber criminals. It's quite appropriate that the same quantum technology that might make today's encryption techniques obsolete could provide a replacement in the form of quantum cryptography.

HEROES OF... SCIENCE

Florence Nightingale proved that trained nurses and cleaner hospitals improved patient recovery

Florence Nightingale

The extraordinary story of the Lady with the Lamp and founder of modern nursing

Born into a wealthy middle-class family, Florence Nightingale was expected to grow up to marry and take care of her home, but she had other ideas. From the age of 16, she believed she had a calling from God, telling her that she should help the sick and injured by becoming a nurse. At the time, nursing was considered a job for poor, elderly women with a reputation for drunkenness and bad language, and so her parents disapproved of her chosen vocation. However, Florence was determined to fulfil what she believed was her moral duty, and travelled to a hospital in Germany to begin training.

By the time she was 33, she was running a hospital for women in London, but then the Crimean War began. British, French and Turkish soldiers were fighting with the Russians, and reports that the wounded were not receiving proper medical care were reaching home. Britain's minister of war was friends with Florence, and so asked her to organise a team of nurses to travel to the Scutari hospital in Turkey and help out.

When Florence and the nurses arrived, they were shocked by what they found. The hospital was filthy, with many of the patients lying among rats on the cold, hard floor, and just about surviving on a diet of mouldy bread and meat. Cholera and typhus were rife, and the unsanitary conditions meant that many soldiers were more likely to die from these diseases than their war wounds.

Florence knew that something needed to be done, but the army doctors were unwelcoming of change. However, as the wards became more overcrowded, they quickly realised help was needed, and so let Florence get to work. She cleaned up the wards, organised more blankets and beds, and arranged for a chef to prepare better meals. After working for 20 hours each day she would then wander around the wards at night with a lantern, checking on the patients. This earned her the nickname 'The Lady with the Lamp' and by the time she returned from the war, she was a heroine.

The British public set up the Nightingale Fund so she could continue her important work, and

A LIFE'S WORK

A closer look at the extraordinary life of one of science's great theoretical thinkers

1820
Florence Nightingale is born in Florence, Italy, on 12 May and named after the city of her birth.

1851
Florence travels to Germany to begin training as a nurse for three months.

1853
Florence becomes the superintendent at a hospital in London for 'invalid gentlewomen'.

1854
Florence travels to the Scutari hospital in Turkey to nurse wounded soldiers.

The big idea

Linking hospital conditions to patient health

During her time at the Scutari hospital, Florence Nightingale compiled detailed reports about the death rates of patients and what improvements could be made in both military and city hospitals. She demonstrated that overcrowding, contaminated water, a poor diet and poor ventilation were causing the spread of diseases, and campaigned for medical reform to improve patients' chances of survival. Passionate about the cause, she wrote letters to Queen Victoria and the prime minister, and eventually succeeded in instigating a Royal Commission into the health of the army. As a result, several improvements were made to ensure the mistakes of the Crimean War were not repeated.

Florence wrote many letters campaigning for medical reform

she used the donations to open a training school for nurses. Her students were given practical training and comfortable living quarters, and were soon requested to start new schools in Australia, America and Africa.

Although Florence spent much of the remainder of her life bedridden due to illness, she continued to campaign for improvements to medical care. By the time she passed away, she had written over 200 books, reports and pamphlets about nursing, and helped transform it into a respectable career for people all around the world.

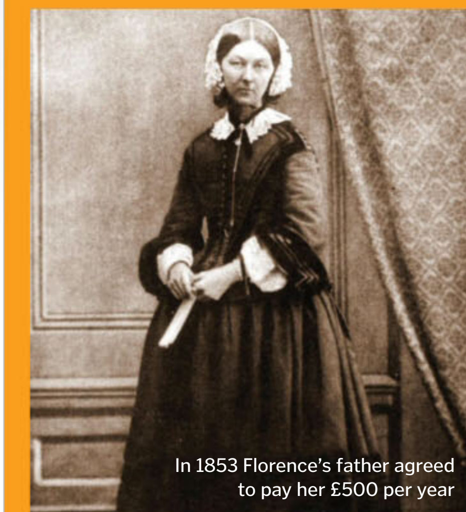
Along with a statue in London, three statues of Florence Nightingale stand in Derby

"The hospital was filthy, with many of the patients lying among rats on the cold, hard floor"

The overcrowded and filthy conditions of the Scutari hospital inspired Florence to campaign for change

An image of Florence as 'The Lady with the Lamp' was first published in the *Illustrated London News* in 1855

Five things to know about… FLORENCE NIGHTINGALE



In 1853 Florence's father agreed to pay her £500 per year

1 She invented a chart
When writing her reports, Florence developed a form of pie chart, called a polar area diagram, to visually represent statistics on death rates in hospitals.

2 She was on the money
An image of Florence and her work in the Scutari hospital appeared on the reverse of £10 notes issued by the Bank of England between 1975 and 1994.

3 Nurses still celebrate her birthday
International Nurses Day falls on the 12 May every year, marking the anniversary of Florence's birth and the important work nurses do all around the world.

4 She didn't enjoy fame
After returning from the war, Florence used the pseudonym Miss Smith to avoid all of the media attention she was receiving as The Lady with the Lamp.

5 She had a pet owl
Nightingale once rescued a baby owl that had fallen from its nest. She named it Athena, trained it to bow and curtsy, and kept it in the pocket of her apron.

1858 Florence becomes the first female member of the Royal Statistical Society.

1859 Florence writes *Notes On Nursing: What It Is And What It Is Not*, a book about good nursing practices.

1860 The Nightingale Training School for nurses opens at St Thomas' Hospital in central London.

1883 Queen Victoria awards Florence Nightingale with the Royal Red Cross for her services to nursing.

1907 Florence becomes the first woman to receive the Order of Merit, Britain's highest civilian decoration.

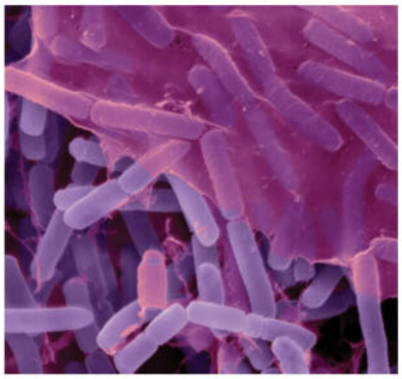
1910 Florence Nightingale dies peacefully in her sleep at her home in Mayfair, London on 13 August, aged 90.

What is a biofilm?

How microorganisms start working together as a giant, gooey mat

Biofilms are layers of microorganisms held together by a sugary glue. The individuals at the bottom anchor themselves tightly to a surface, and the ones living in the layers above remain connected by a gel that shares genetic information and chemical signals. Together, they are stronger and more resilient than they would be alone.

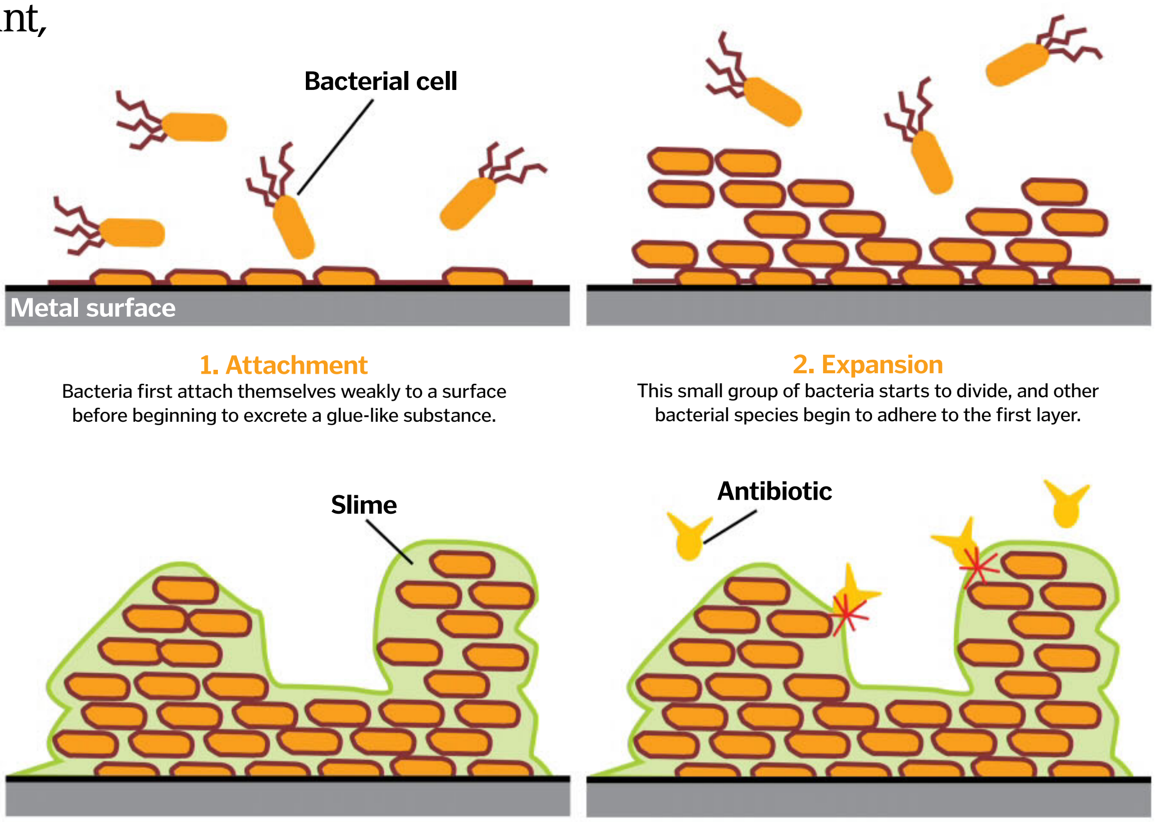
These living structures can grow on medical implants, inside water pipes, and even on your teeth as plaque. They cling so tightly that they can't just be washed away, and their protective film provides some shielding against antibiotics and the immune system, making them even harder to get rid of.



Most ear infections are caused by biofilms

Building a biofilm

What starts as a few bacteria can quickly grow to become a whole community



1. Attachment
Bacteria first attach themselves weakly to a surface before beginning to excrete a glue-like substance.

2. Expansion
This small group of bacteria starts to divide, and other bacterial species begin to adhere to the first layer.

3. Maturation
The bacteria start working together as a community. They produce a sticky film, sharing nutrients and communicating.

4. Resistance
The community can withstand assault from the outside, fending off toxic chemicals, drugs, and even the immune system.

The science of hair gel

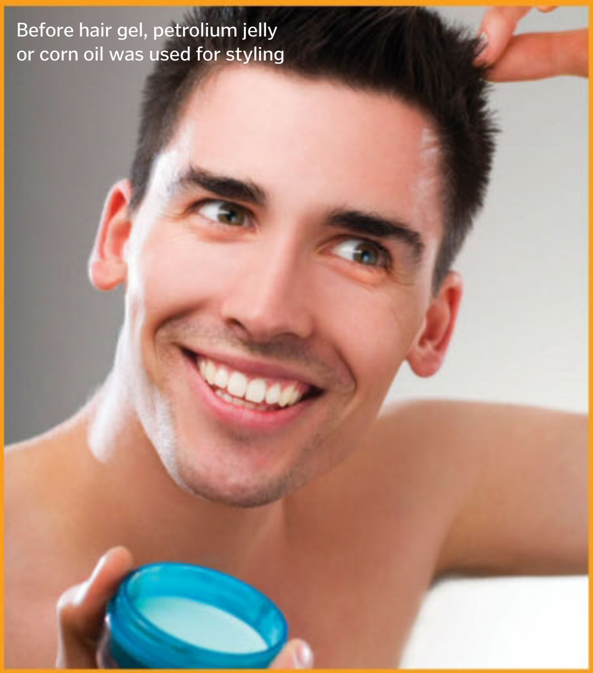
How does this produce get your wayward strands to stay perfectly still?

Hair gel is a 'hydrogel', made from long molecules known as polymers. The polymers are made from smaller building blocks called monomers, and when these are strung together, they are capable of holding several times their own weight in liquid water.

The polymers are bound to water when the gel is in its container, and this changes their structure and gives the monomer components a charge. Negative charges appear down the length of the polymer, and these repel each other like magnets. This straightens and lengthens the chains, and as this happens, water gets pulled in.

Water molecules have a slight positive charge on one side, and a slight negative charge on the other, so as they try to flow past the charges on the chains, they are slowed down. And when water molecules become trapped between the strands, the result is a thick, gloopy gel.

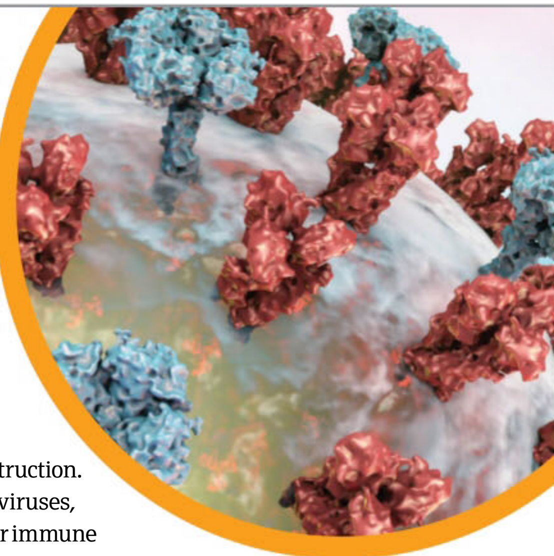
When the gel is used to style hair, the water starts to evaporate. This leaves a web of long, knotted molecules behind, holding your hairstyle in place until it is washed away.



Before hair gel, petroleum jelly or corn oil was used for styling

Bacteria vs virus

Which is which, and why does it even matter?



The flu virus is covered in molecules that help it to get inside cells

When you've got a sore throat, the cause doesn't always seem important. Some microscopic nasty is waging war with your immune system, it hurts, and you just want to feel better. But whether it's bacteria or a virus on the rampage is actually very important.

Bacteria are some of the smallest living things on the planet, each made from just a single, primitive cell. Their insides are separated from the outside by a fatty membrane and a flexible coat of armour called the cell wall. Their genetic information is carried on loops of DNA, and these contain tiny factories called ribosomes, which use the genetic code to produce the molecules that the bacteria need to grow, divide and survive.

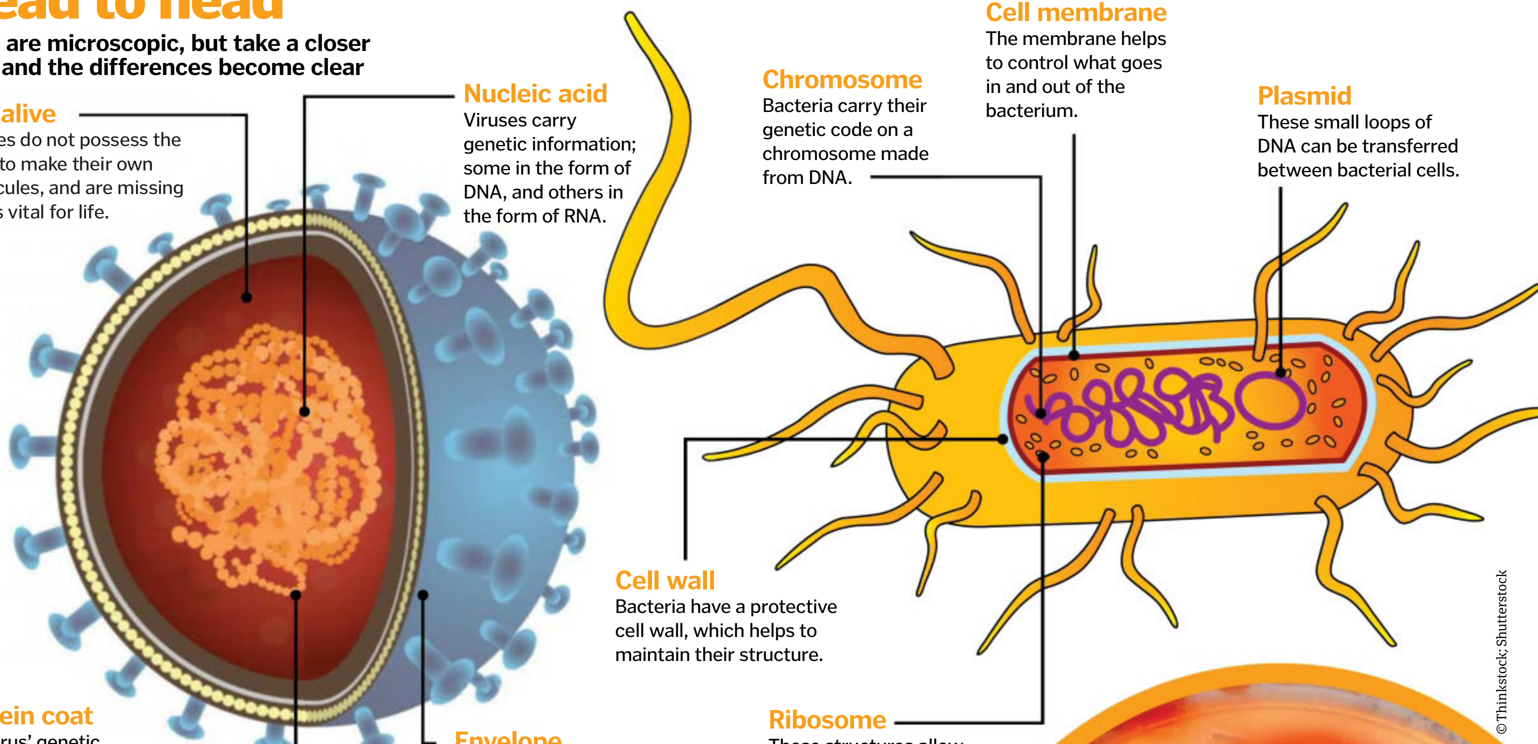
Viruses, on the other hand, are not technically alive. They carry genetic information containing the instructions to build more virus particles, but they don't have the equipment to make molecules themselves. To reproduce, they need to get inside a living cell and hijack its machinery, turning it into a virus factory.

Both bacteria and viruses can cause diseases, but knowing which is the culprit is critical to treating them effectively. Antibiotics can harm bacteria, but have no effect on viruses. Even your own immune system uses different tactics.

For bacteria, it unleashes antibodies – projectile weapons that stick invading microbes together, slowing them down and marking them for destruction. For viruses, your immune system can search for any infected cells before initiating a self-destruct sequence to dispose of anything lurking inside. But some viruses are able to endure our defences, and can remain inside us indefinitely.

Head to head

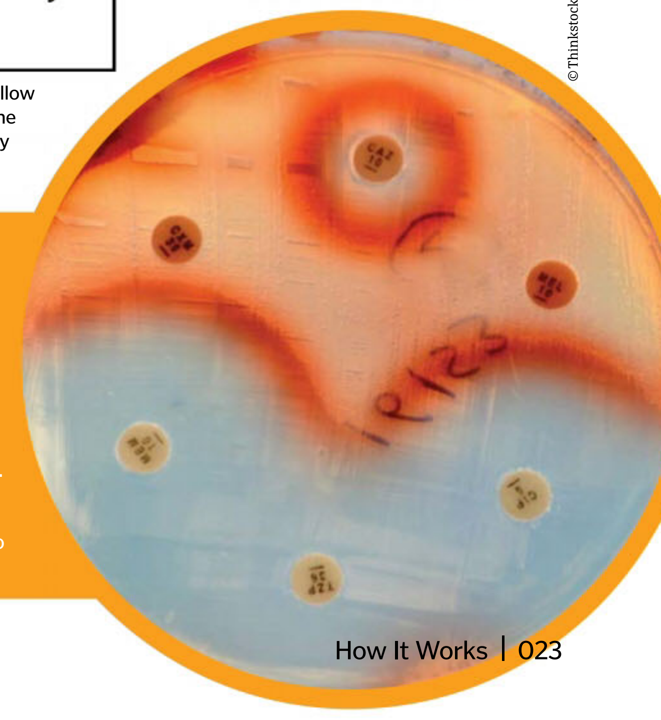
Both are microscopic, but take a closer look and the differences become clear



"For viruses to reproduce, they need to get inside a living cell and hijack its machinery, turning it into a virus factory"

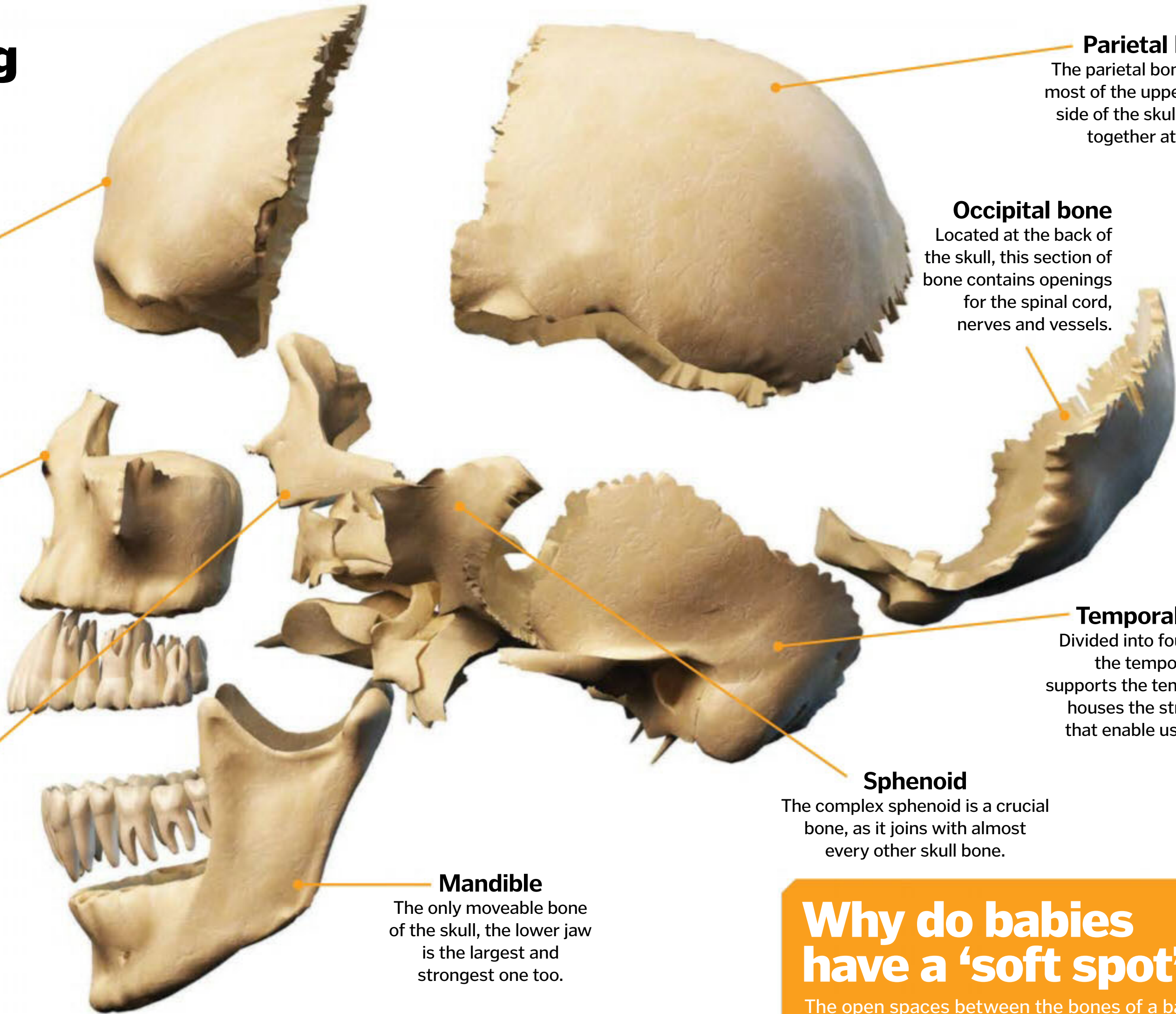
Antibiotic resistance

Antibiotics attack bacteria. They work by interrupting the way that the tiny cells divide, grow and repair. However, if an infection is caused by a virus, antibiotics won't help. Viruses don't work in the same way as bacteria, so antibiotics can't help to fend them off. It might not seem like much of a problem, but every time antibiotics are used, it gives bacteria a chance to learn how to resist them. So every time a patient with a virus is given antibiotics, not only will they not get better, but bacteria lurking in their bodies will have a chance to see the drug and develop defences against it.



Breaking it down

How the various bones fit together to form the skull



The human skull

Understand the complex structure that supports our brain and facial tissues

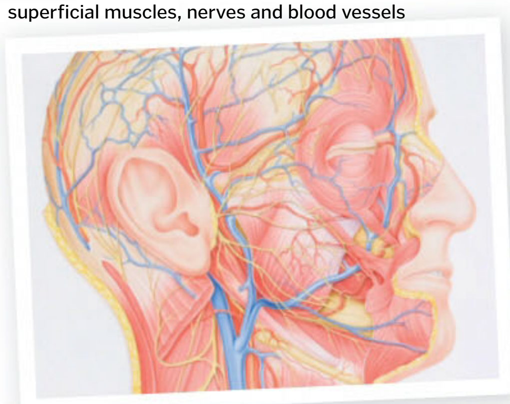
The human skull is made up of 22 bones that fall into two primary groups: the cranium, which consists of eight 'cranial' bones, and the facial skeleton, which consists of 14 facial bones. These bones are joined together by fibrous joints known as sutures. Unique to the skull, once these joints have fused together by the age of around 30 to 40, they are immovable.

The cranium consists of a roof part – known as the calvarium – and a complex base part. The calvarium helps to cover the cranial cavity, which the brain occupies, along with flat bones at the top and sides. The base of the brain case is divided into large spaces, and has various openings for the passages of cranial nerves, blood vessels and the spinal cord.

The facial skeleton provides support for the soft facial tissues, and its bones fuse together to house the orbits of the eyes, nasal and oral cavities, in addition to the sinuses. Only one of the skull's 22 bones is moveable, and that is the lower jaw.

As you can see in the diagram above, the skull is a complex structure, but then its main roles are to protect the brain and support the face, so this comes as no surprise.

The skull does an impressive job of protecting superficial muscles, nerves and blood vessels



Why do babies have a 'soft spot'?

The open spaces between the bones of a baby's skull where the sutures intersect are called fontanelles. Covered in a protective membrane, there are two kinds of fontanelles: the anterior fontanelle – also known as the 'soft spot' – and the posterior fontanelle. The anterior fontanelle is where the two frontal and two parietal bones meet, and this area stays soft until the age of around two. The posterior fontanelle is where the two parietal bones and the occipital bone meet, and this area usually closes when a baby is a few months old.

The formation occurs as a means of helping the baby's head fit through the birth canal. The reason they remain open for some time is to enable the brain to develop and grow. It's important that the fontanelles don't close up too early – a process known as craniosynostosis – as this can result in various medical problems.

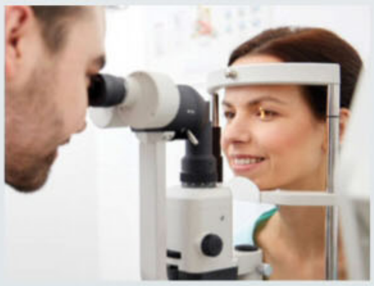
The anterior fontanelle is positioned at the front of the skull

Eye exams

The tests and technology that help determine if you have healthy vision

Slit lamp exam

A slit lamp machine is used to examine the front, inside and back of your eyes. Using bright light and a series of magnifying lenses, eye care specialists can see the entire eye structure and identify any problems.



A slit lamp is a powerful microscope used to examine the eyes

Autorefractor

An autorefractor determines the correct lens prescription for your eyes. It works by shining a light into your eyes when they are properly focused on an image and measuring how it reflects off the retina.

An autorefractor is used to work out what lenses you need

Ophthalmoscope

Typically used after your eyes have been dilated, this handheld instrument helps to examine the interior of your eyes. It features a light source and built-in mirrors and lenses to magnify the retina.

An ophthalmoscope helps your eye doctor look for symptoms of diseases

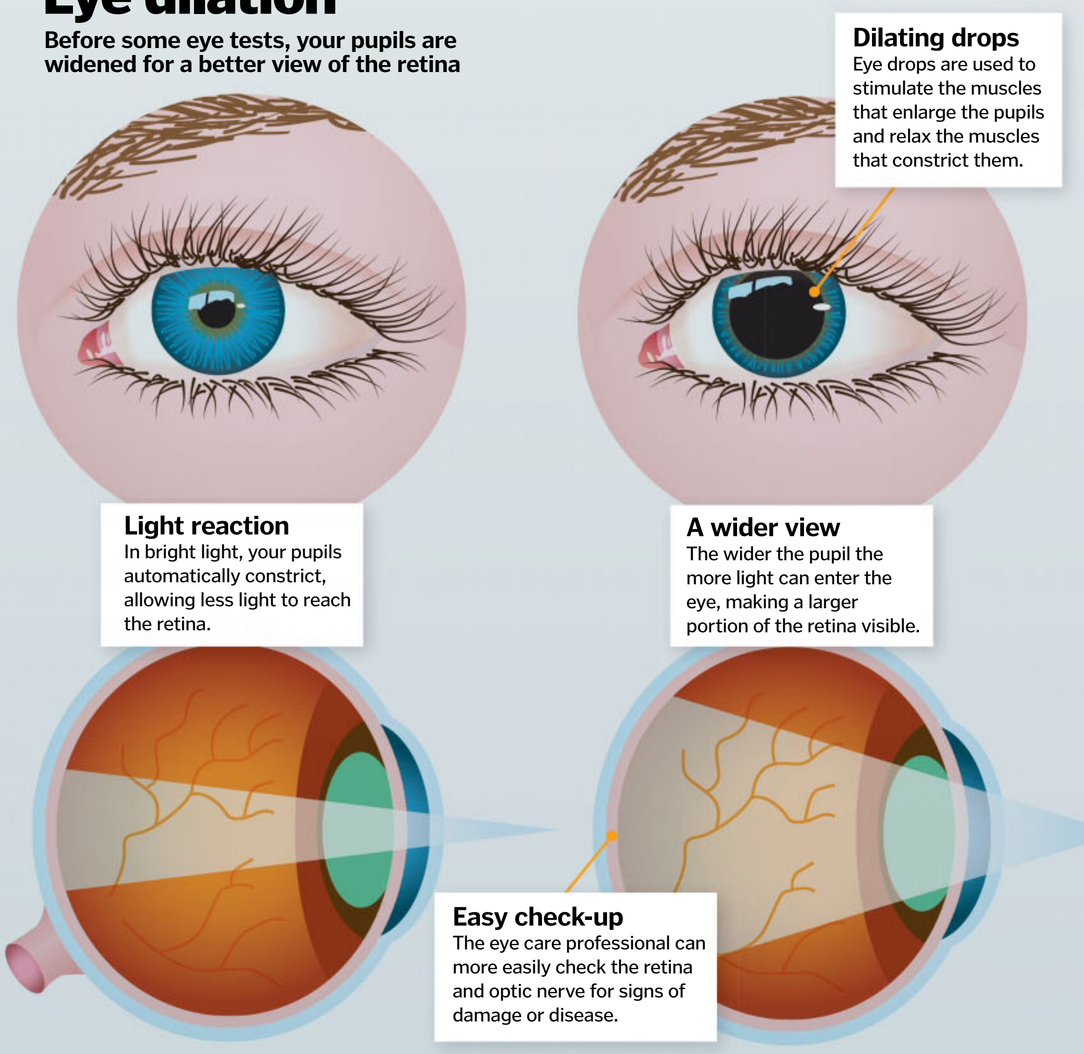
Tonometer

A tonometer is used to blow a puff of air across the surface of your eye. By measuring the eye's resistance to the air, its internal pressure can be calculated. High pressure could be an indicator of glaucoma.

Glaucoma is a disease that attacks the optic nerve

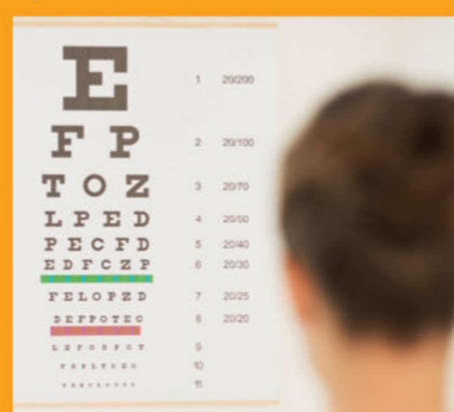
Eye dilation

Before some eye tests, your pupils are widened for a better view of the retina



What exactly is 20/20 vision?

The most familiar type of eye test is the Snellen eye chart, which features a pyramid of letters. It usually has a large 'E' at the top – it is sometimes called a Big 'E' chart – followed by rows of other specifically chosen letters descending in size order. Your eye care professional will get you to read each line from top to bottom, with one eye covered each time. The point at which the letters become difficult to see is the measurement of the sharpness of your vision. If you are standing 20 feet (6.1 metres) away from the chart and can comfortably see the letters most people with normal vision can see at that distance, then you have 20/20 vision. However, if the letters you can only see comfortably at 20 feet can be seen by a person with normal vision at 30 feet (9.1 metres), this means that you have weaker 20/30 vision.



The Snellen chart is used to determine if you have 20/20 vision

CORAL REEFS

2016 saw some surprising discoveries in the study of coral, including brand-new reefs

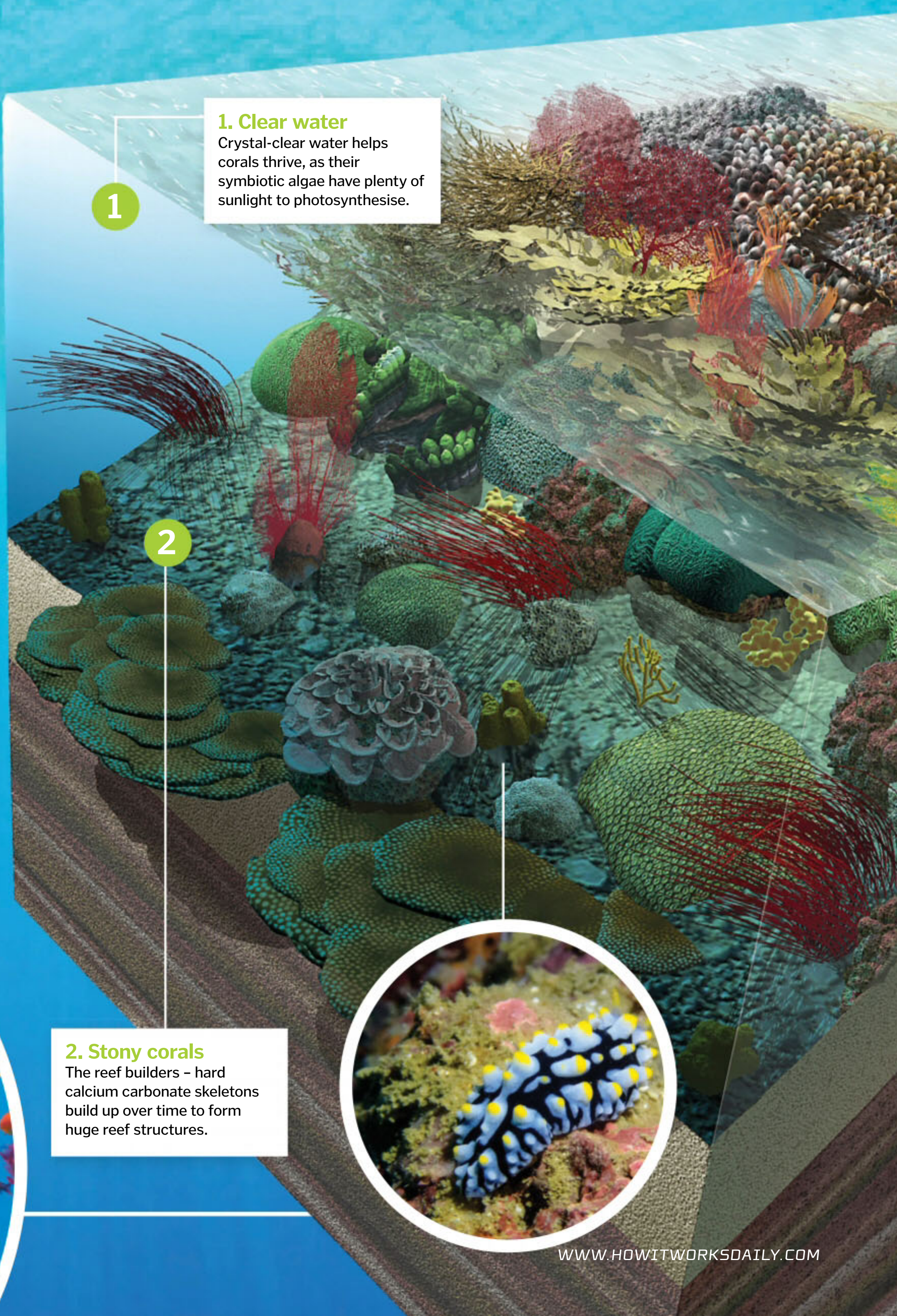
A coral polyp on its own can measure just a few millimetres in size, but when it joins with others to form a colony, and the colony joins with other species to make a reef, those tiny polyps create one of the largest structures on Earth. It's thought that coral reefs contain 25 per cent of our planet's biodiversity, but cover just 0.2 per cent of its surface!

There are two types: hard and soft. The hard corals are the reef architects – they secrete a hard, slow-growing skeleton of calcium carbonate that fuses together over time to create the giant, natural barriers. Soft corals secrete skeletons that aren't as tough, but they still play a key part in reef growth and health.

The corals that grow in the shallows need super clear water, as light is essential for their growth. Their tissues contain tiny algal cells called zooxanthellae that photosynthesise and provide the coral with food. The algae also gives the coral its tropical, vibrant hue, turning the reef into a riot of submarine colour.

Deep-water corals don't rely on symbiotic algae for food because they live in the dark, so instead they catch their own. Corals have a surprising method of predation. Each individual polyp in a colony has stinging cells called nematocysts that are triggered by touch. Depending on the species, the nematocysts can deliver a powerful and sometimes lethal toxin, allowing the coral to take down prey.

With everything in delicate balance, coral reefs that live near land often rely on other

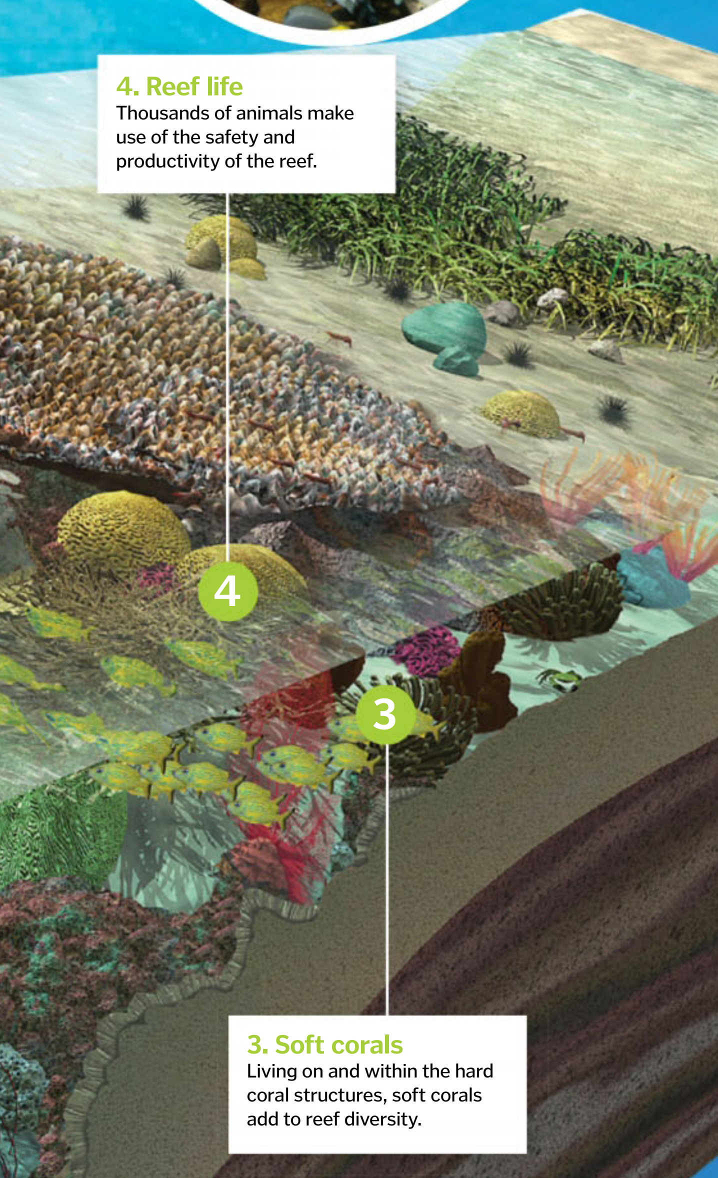


1. Clear water
Crystal-clear water helps corals thrive, as their symbiotic algae have plenty of sunlight to photosynthesise.

2. Stony corals
The reef builders – hard calcium carbonate skeletons build up over time to form huge reef structures.

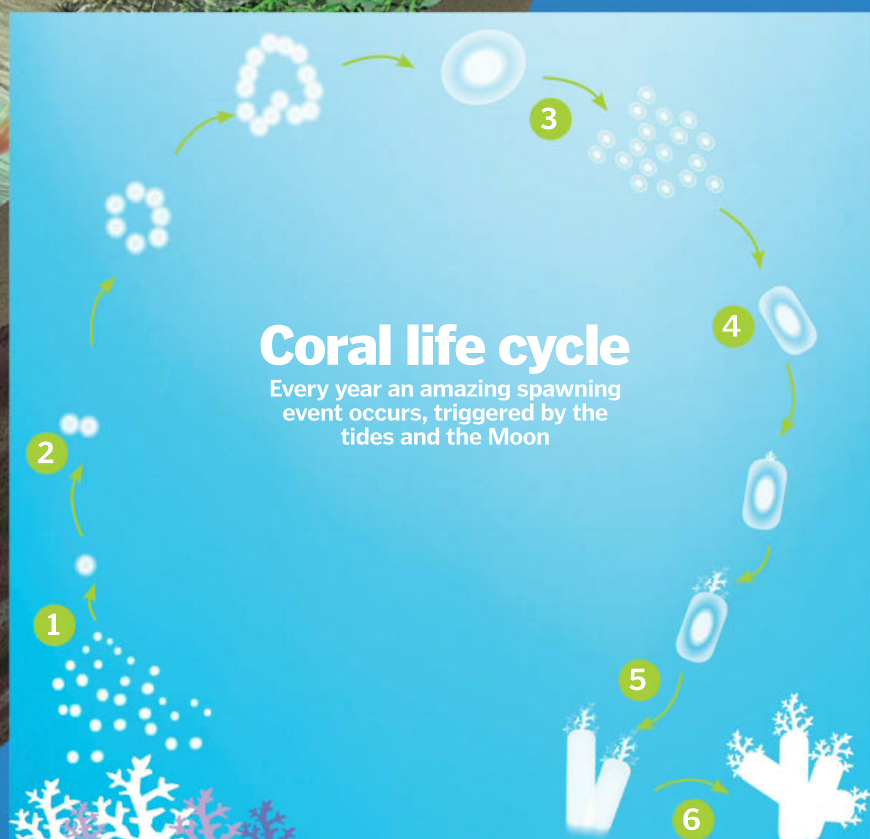
Reef essentials

For most coral reefs to flourish they need clear water and plenty of sunlight



4. Reef life
Thousands of animals make use of the safety and productivity of the reef.

3. Soft corals
Living on and within the hard coral structures, soft corals add to reef diversity.



Coral life cycle

Every year an amazing spawning event occurs, triggered by the tides and the Moon

1. Spawning
Corals release both sperm and eggs into the water at the same time.

2. Rising
Many eggs are soon fertilised. The cells rise to the surface and begin to divide.

3. Larvae
The cells drift and continue to divide until they have developed into coral larvae.

4. Substrate
Once the larvae are large enough, they begin to sink toward the ocean floor.

5. Settling
Once settled, hard coral starts to produce a skeleton of calcium carbonate.

6. Growth & maturity
Growing mere centimetres annually, it takes many years for a new coral reef to form.

interlinked ecosystems nearby to thrive. Mangroves are important, as these salt-water trees trap sediment and run-off from the land, filtering pollution and providing nutrients. Their long, submerged roots are also important nursery grounds for species that then make their way to the reef as adults.

Similarly, seagrass meadows often grow between mangroves and reefs, providing essential food for grazers and stabilising the seabed, keeping the water clean. Research has also shown that coral reefs that grow in conjunction with mangroves may not be as susceptible to bleaching.

Coral bleaching events happen when the corals undergo thermal stress. To thrive, most tropical coral species need a water temperature of 18-29 degrees Celsius; they are highly sensitive to temperature fluctuation. If water temperatures get too high, the corals react by expelling their symbiotic zooxanthellae. This turns them a bright white colour, which can eventually lead to their death.

2016 saw one of the worst ever coral bleaching events. As sea surface temperatures have risen by one degree Celsius over the last century, corals have been pushed to the brink. Some 67 per cent of corals were affected in the worst-hit areas of the Great Barrier Reef and some publications even published obituaries for the marine site. But luckily, for now, the Great Barrier Reef still prevails.

There are some coral types that have already adapted to temperature extremes – the corals of Kimberley in western Australia make up one such reef. The area has the largest tropical tides in the world (up to ten metres) and the corals are repeatedly exposed to the air and soaring midday temperatures, as well as super-heated stagnant tidal pools. These conditions would be deadly to coral species living elsewhere, but the Kimberley corals flourish! Interestingly, the corals exposed to these extremes showed a better resistance to hot water when tested, indicating that a highly variable environment may hint to bleaching resistance in corals.

Certain corals seem to withstand bleaching better than others

"The fast-growing algae deposits a calcium carbonate skeleton as it ages, like rings on a tree"

Some coral reefs have a symbiotic relationship with nearby mangroves

Cold-water reefs

Not all corals are found in tropical water; in fact, some of the most widespread corals found in all ocean basins are in deep water. These amazing species don't need light or photosynthesising zooxanthellae to survive, and they are able to expand and thrive in the depths of complete darkness, albeit slowly. They get their energy and nutrients by catching food particles that float by in the water.

These coral types prefer to live in areas with fast-flowing currents where food will be plentiful, such as continental shelves, seamounts, ledges and pinnacles. They have even been found living in water as cold as -1 degree Celsius and as far south as Antarctic waters.

The largest cold-water coral reef is off the coast of Røst Island in Norway, which measures around 40 kilometres in length. Like warm-water reefs, the cold-water varieties provide a haven for all kinds of marine life, including starfish and worms.

Cold-water corals have a wide distribution because they do not rely on sunlight to survive

The secret reef

Hiding behind the Great Barrier Reef is another giant reef system that until 2016 was largely unknown. Nicknamed the 'doughnut reef', it is primarily comprised of bioherms – large calcified structures left behind and built upon by the green algae halimeda.

Scientists were shocked to see that the bioherm reef covers a whopping 5,957 square kilometres. All was revealed when high-resolution airborne LiDAR technology was used to create an accurate 3D map of the seafloor.

The bioherms are much deeper than the Great Barrier Reef, but it is estimated they are approximately the same age. Some of the amazing structures measure nine metres high and over 180 metres across. The fast-growing algae deposits a calcium carbonate skeleton as it ages, like rings on a tree, allowing researchers to see the age of the bioherms. Studying these structures also allows scientists to tap into records of ocean temperature and acidity that date back to the last Ice Age contained within the mineral deposits.

The new bioherm reef was discovered by an aerial study using LiDAR

The Amazon Reef

Last year, scientists discovered a reef in a very surprising location…

Probably the most surprising coral reef is the one beneath the murky outflow of the Amazon River, off Brazil's Atlantic coast. The 6,992-kilometre-long river discharges huge volumes of mud and freshwater into the sea every year, increasing the salinity and turbidity of the water there – entirely the opposite of the conditions that traditional coral reefs need to thrive. The reef was found in 2016, but researchers were first brought to the possibility of a reef in the area in 1970, when they caught species of reef fish in trawls. Using multibeam acoustic sampling the team explored the deep waters along the continental shelf from the surface and were able to find and map the reef that lay beneath the plume of sediment-laden freshwater. They then used trawls, dredges and box corers to bring up samples of fish, sponges, coral and all kinds of other species to gain an idea of what life is flourishing beneath the mud.

The huge plume of Amazon sediment-laden water can clearly be seen in satellite images

The river reef revealed

Beneath sediment-laden fresh water is an incredible ecosystem full of life

Amazonian plume
The north reef is where the sediment load from the plume is highest and little light gets through.

Beneath the mud
Deep water and ocean currents take the fresh water plume away from the reef, allowing to survive beneath.

Variable sediment
The sediment load in waters above the central reef is very variable, depending on different environmental factors.

Clearer waters
The south section of the reef is less affected by the plume – waters here are clearer and more sunlight can penetrate.

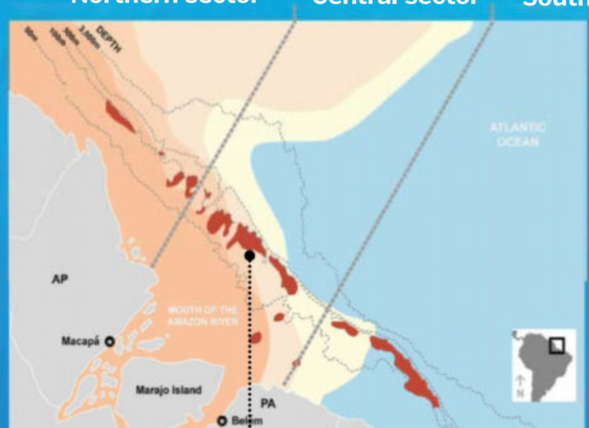
North reef
This reef on the muddy bottom is thousands of years old. It has stopped growing and is populated with giant sponges.

Central reef
Lobsters and sponges thrive on this reef, as well as rhodoliths – coral-like forms of crusting red algae.

South reef
This reef is more like traditional coral reefs, with an abundance of hard and soft corals and many animal inhabitants.

Maximum extent of the sediment plume during the year:
- Nov–Jan
- Feb–Apr
- May–Jul
- Aug–Oct
- Reefs

Northern sector **Central sector** **Southern sector**



Reef size
Sitting off the coast of Brazil and French Guinea, the reef covers 9,500 square kilometres – an area roughly the size of Cyprus.

Reef species
In total, researchers found over 60 species of sponges and 73 species of fish.

Another incredible adaptation of coral is the 'phoenix affect'. In 1998 a disastrous coral bleaching event killed off nearly 16 per cent of the world's corals. Divers in Rangiroa Lagoon in French Polynesia had noticed that the super-hardy porites corals had also succumbed to bleaching and projected that, based on growing rates, it would take the reef over 100 years to recover. However, 15 years later those same divers returned to find the reef back to the thriving oasis it had once been..

One theory about how the corals were able to recover so quickly is that perhaps the giant structures aren't as 'dead' as first thought. It's believed that if some of the colony tissue hidden deep within the skeleton was more protected, then it was able to recolonise across the original skeleton once temperatures improved.

Another astounding discovery from 2016 was the Amazon Reef, an extensive deep-water reef system of sponges, corals and rhodoliths living precisely where scientists never thought corals could – under the muddy sediment plume of the mouth of the Amazon River. 120 kilometres off the coasts of Brazil and French Guinea, between 50 and 100 metres below the water's surface, the reef sits unencumbered by the river outflow.

The topography of the seabed and the intensity of the currents mean that the slick of sediment-laden fresh water that spills from the Amazon doesn't reach deep enough to affect the corals, which need a saline environment to thrive. Despite having lower biodiversity than expected in an established warm-water reef, it is an incredible oceanographic discovery.

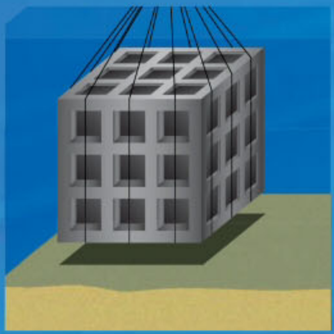
New techniques in remote sensing are making it even easier to study coral reefs and get a clearer picture of how they work and the state of their health worldwide. We can view reefs from the air and from the sea with state of the art equipment like ROVs. We can even analyse coral (live and fossilised) to learn more about Earth's prehistoric climate by analysing the chemical properties of their skeletons.

Coral reefs provide a habitat and food for fish that we eat, they protect our land from storms and erosion, they dissipate wave energy and reefs also provide thousands of jobs for people worldwide. Despite coral being an incredibly hardy and resilient creature, it is still under threat from ocean acidification and warming temperatures. The loss of a reef can cause a catastrophic ecosystem shift where great swathes of ocean life suffer as a consequence. They are tough, but coral also need protection so that generations to come may enjoy the same reef benefits as we do today.

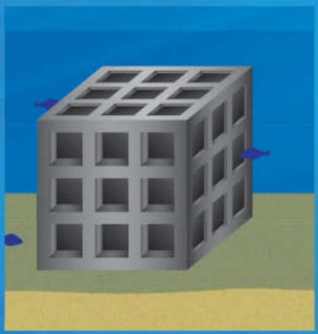
Artificial reefs

An artificial reef is anything in the sea built by humans that has been colonised by coral and algae or other encrusting species. Oil platforms, piers, jetties and sunken debris are all artificial reefs, providing substrate for all kinds of marine life to cling to, which in turn brings fish and many other creatures to the reef in search of the food and protection available.

Many reefs have been sunk deliberately to encourage marine life to an otherwise featureless location, such as decommissioned warships, train carriages and out-of-service oil rigs. Settlers begin to arrive almost immediately, and after a few months marine life will be flourishing on the underwater structure.



Placement
The structure is placed in a marine location usually devoid of life. Purpose-built reefs are made of pH-balanced material and feature hollows and indentations to attract settlers big and small.



Within weeks
The first settlers, such as sedentary organisms like sponges, anemones and barnacles, are encrusting. Small fish such as snappers will soon be attracted to inspect and graze on the growing colonists.

Within years
A fully developed artificial reef will have calcareous coral species settled on it in a matter of years. The smaller fish attract much larger predators, completing a complex and balanced food web.

Climate change and coral reefs

As our planet warms its coral reefs are at risk from varying factors and threats

Warming ocean

Rising temperatures induce thermal stress in corals. They expel their symbiotic zooxanthellae and whole colonies can die in a process called bleaching. Temperature increases also raise the risk of diseases.

Sea level rise

This can be accompanied with higher levels of sedimentation, which can smother coral and also pollute the water. This prevents sunlight from reaching the zooxanthellae, so they cannot photosynthesise for the coral.

Storms

Climate change can affect the intensity, frequency and distribution of storm patterns. Although reefs can recover from storm damage, this takes time. A period of storms may severely damage a reef.

The CORAL programme

In an effort to better understand our oceans, NASA have turned their gaze on the world of coral

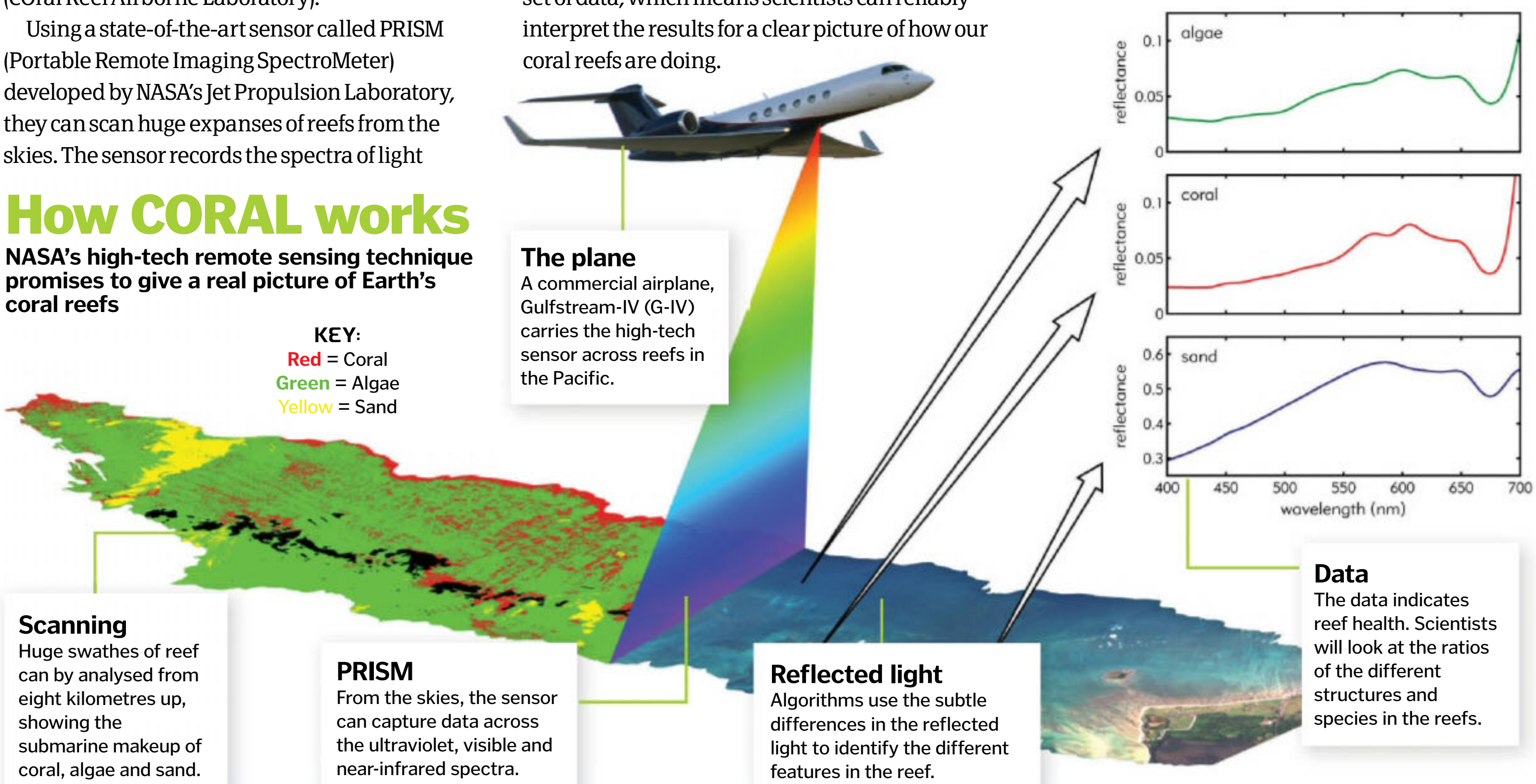
Coral reefs are essential ecosystems in our oceans and much research has been done into their health and protection, however all of these data sets have been collated under different parameters. To combat this, 2016 saw NASA launch a $15 million initiative called CORAL (COral Reef Airborne Laboratory).

Using a state-of-the-art sensor called PRISM (Portable Remote Imaging SpectroMeter) developed by NASA's Jet Propulsion Laboratory, they can scan huge expanses of reefs from the skies. The sensor records the spectra of light reflected upwards from the ocean below. An algorithm removes the influence of the water and allows researchers to get a realistic picture of coral, algae and sand – important factors for assessing reef health. CORAL will scan reefs across the Pacific, from Australia to Hawaii, to gain a uniform set of data, which means scientists can reliably interpret the results for a clear picture of how our coral reefs are doing.

The Great Barrier Reef extends for 2,300 kilometres along the northeast coast of Australia

How CORAL works

NASA's high-tech remote sensing technique promises to give a real picture of Earth's coral reefs



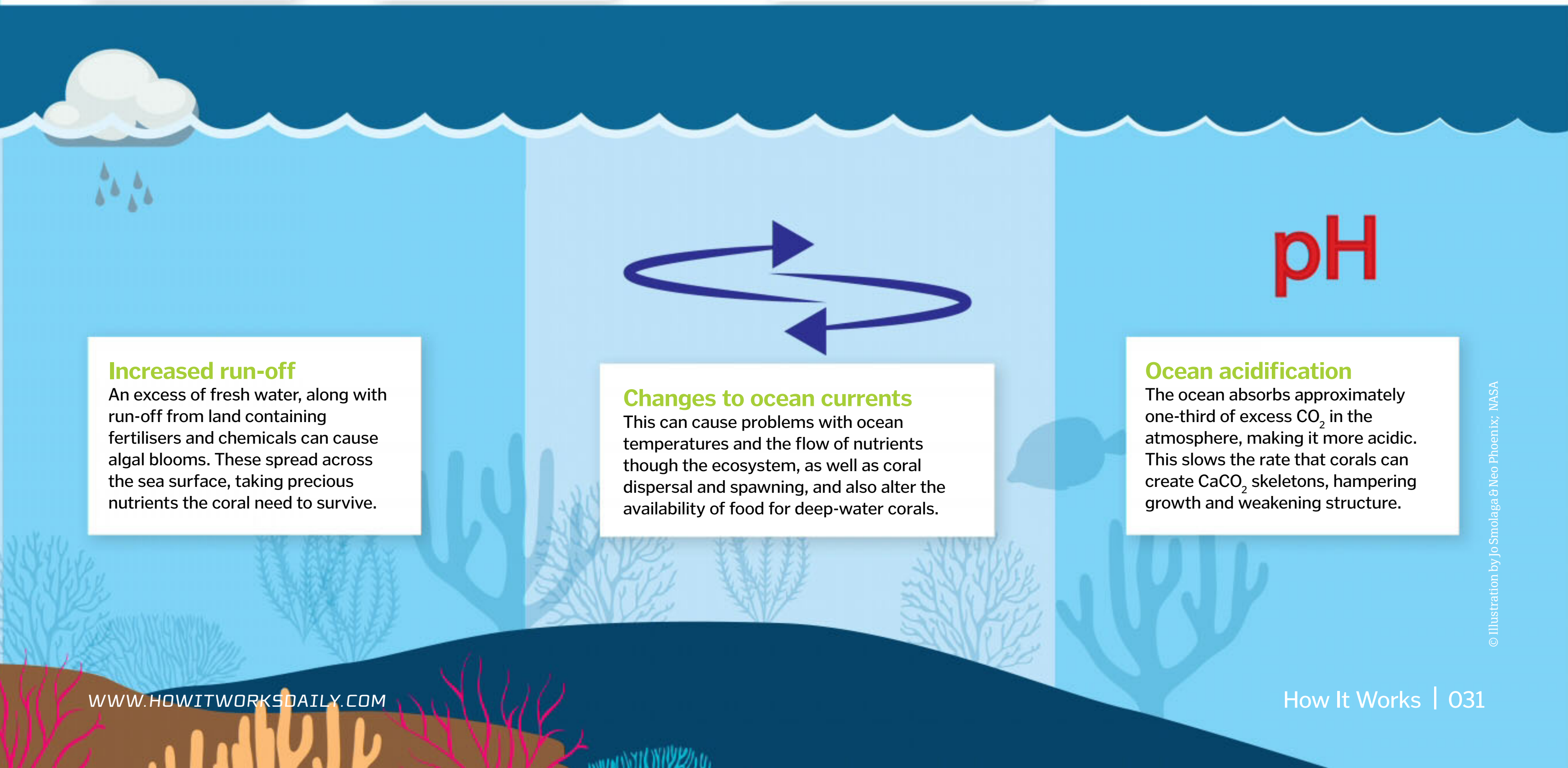
The plane
A commercial airplane, Gulfstream-IV (G-IV) carries the high-tech sensor across reefs in the Pacific.

Scanning
Huge swathes of reef can by analysed from eight kilometres up, showing the submarine makeup of coral, algae and sand.

PRISM
From the skies, the sensor can capture data across the ultraviolet, visible and near-infrared spectra.

Reflected light
Algorithms use the subtle differences in the reflected light to identify the different features in the reef.

Data
The data indicates reef health. Scientists will look at the ratios of the different structures and species in the reefs.



Increased run-off
An excess of fresh water, along with run-off from land containing fertilisers and chemicals can cause algal blooms. These spread across the sea surface, taking precious nutrients the coral need to survive.

Changes to ocean currents
This can cause problems with ocean temperatures and the flow of nutrients though the ecosystem, as well as coral dispersal and spawning, and also alter the availability of food for deep-water corals.

Ocean acidification
The ocean absorbs approximately one-third of excess CO_2 in the atmosphere, making it more acidic. This slows the rate that corals can create $CaCO_2$ skeletons, hampering growth and weakening structure.

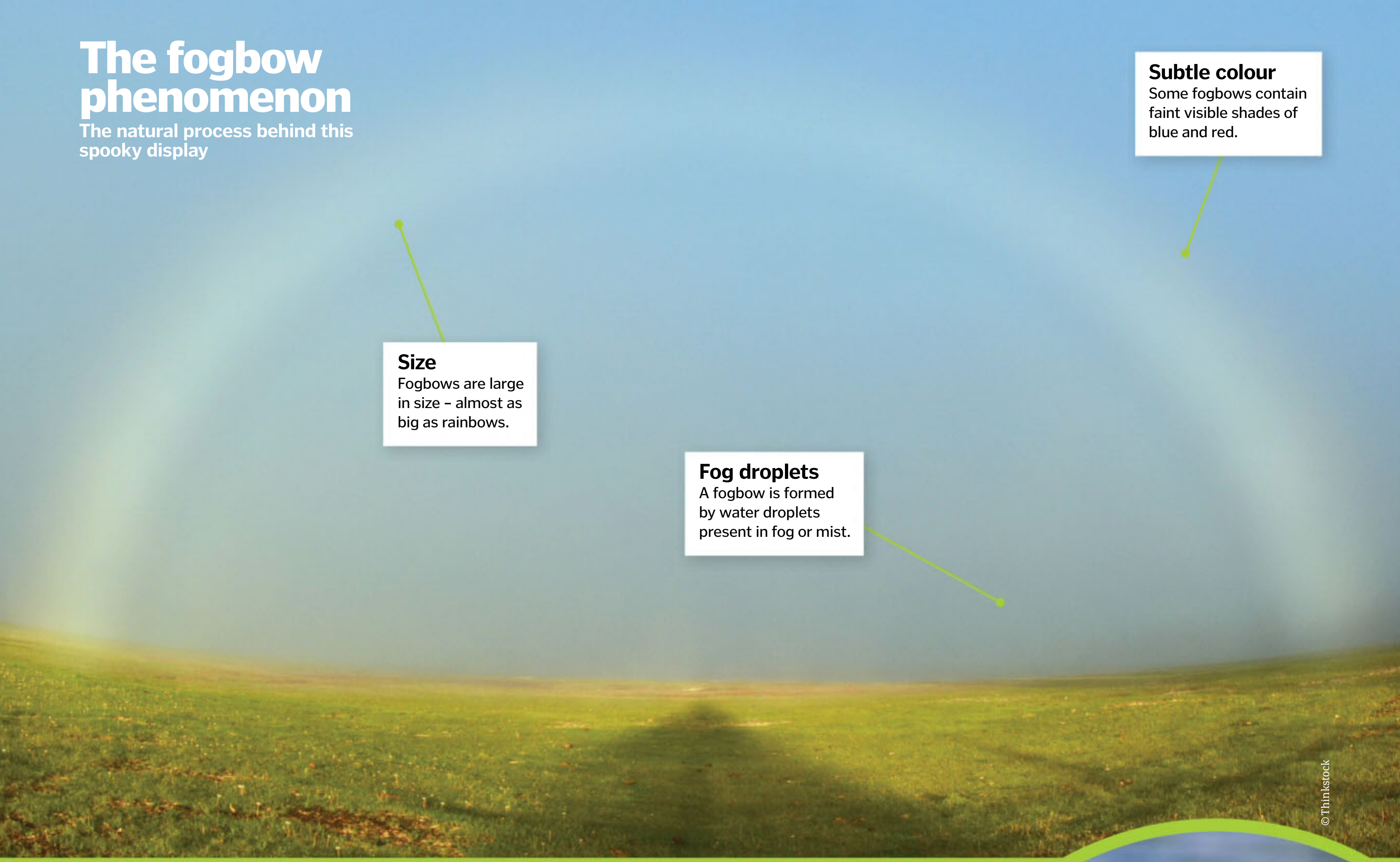
Fogbows

How does a fogbow form, and is it really very different to a rainbow?

A fogbow is similar to a rainbow in the sense that it is created from the same process of sunlight refraction and reflection. However, rather than being formed by raindrops, a fogbow is formed by the water droplets found in fog, mist or cloud. Although sunlight enters, and reflects from, the droplets, forming a large circle opposite the Sun – just as it does when a rainbow is formed – fog droplets are much smaller than raindrops, causing the light to diffract. The diffraction process dominates the reflection process, resulting in a colourless phenomenon. Although colour is present, the bow in each colour is so broad that the colours overlap, resulting in this washed-out effect.

The fogbow phenomenon

The natural process behind this spooky display



Subtle colour
Some fogbows contain faint visible shades of blue and red.

Size
Fogbows are large in size – almost as big as rainbows.

Fog droplets
A fogbow is formed by water droplets present in fog or mist.

Imprinting

How and why do some animals fixate on certain objects?

Imprinting is a behavioural form of learning through which an animal is able to recognise and fixate on the first object it sees, hears or touches. Naturally, this is usually a parent, but sometimes it can be another animal, or even an inanimate object. The young becomes socially attached to the object, following it around.

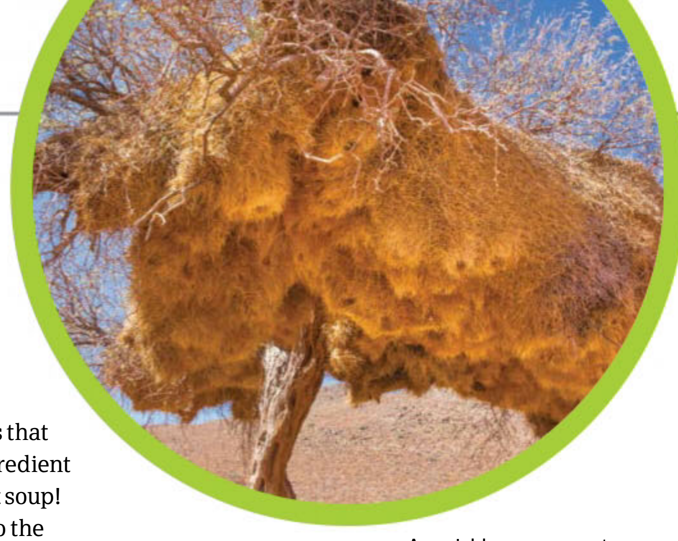
This behaviour has its advantages if the animal imprints on a parent, because it acts as a form of protection and aids the newborn in its search for food. It also means that the young animal is less likely to become separated from its parents, particularly useful when living among animals of the same species.

There is only a short space of time after the animal is born in which imprinting can take place – handy, since it's likely to only encounter its parents in this time. Scientists suggest that once an animal has imprinted, it cannot imprint again. When it does encounter other animals, the risk of becoming separated from its parents is therefore greatly reduced.

Imprinting most commonly takes place among birds

Bird nests

All you've ever wanted to know about the varied and intricate process of nest building



A sociable weaver nest – they live in colonies of over 100 breeding pairs

A nest is a unique structure built by breeding birds as a safe haven for their eggs and young. The nest is highly tailored to suit the bird's ecosystem and life history. For example, seabirds often roost on open ledges high up from the clutches of predators, while species such as the great hornbill in Southeast Asia actually blocks itself into its nest to keep predators away. Other birds, like some kingfisher species, find safety in nests underground, and then there are the stronger species, like mute swans, that set up camp in the open.

Nest materials are also highly specialised to the bird's habitat. One example is the ruby-throated hummingbird, which uses readily available spider silk to bind their nests together. Other birds don't use any other materials at all save for their own saliva. The edible-nest swiftlet is one such bird. Native to Southeast Asia, these small birds produce tiny wafer-like nests that are collected and served as the main ingredient of a popular Chinese delicacy: bird's nest soup!

For some birds, the nest is a way to woo the ladies. Males will build their nests to show off their skills, attracting the females with their handiwork. In other species, the birds will build their nest together in breeding pairs, seeking out materials such as grasses and twigs to weave the structure, and then items like feathers, fur and moss for insulation. This is essential because altricial birds are born featherless, and so need extra protection in their first few days of life.

> "Ruby-throated hummingbirds use spider silk to bind their nests together"

Types of nests

From holes in the ground to majestic skyward structures, nests are very diverse

Dome nest
Animals such as the ovenbird create elaborate mud-baked nests complete with a nesting chamber, corridor and front entrance. These birds use thousands of mud pellets to painstakingly build their nest.

Ground nest
Also known as 'scrape nests', these aren't really nests at all, but a small depression in the ground that birds such as quail, ducks and falcons lay their eggs in.

Burrow nest
Burrows provide excellent protection from predators and maintain constant temperatures for eggs and hatchlings. Some birds, like the European bee eater, dig their own, while others nest in pre-dug underground sites.

Land mound nest
Australian malleefowl make a mound of sand and leaf litter up to four metres across and one metre high. Heat is regulated from a pile of leaf litter in the centre of the nest, which incubates the eggs.

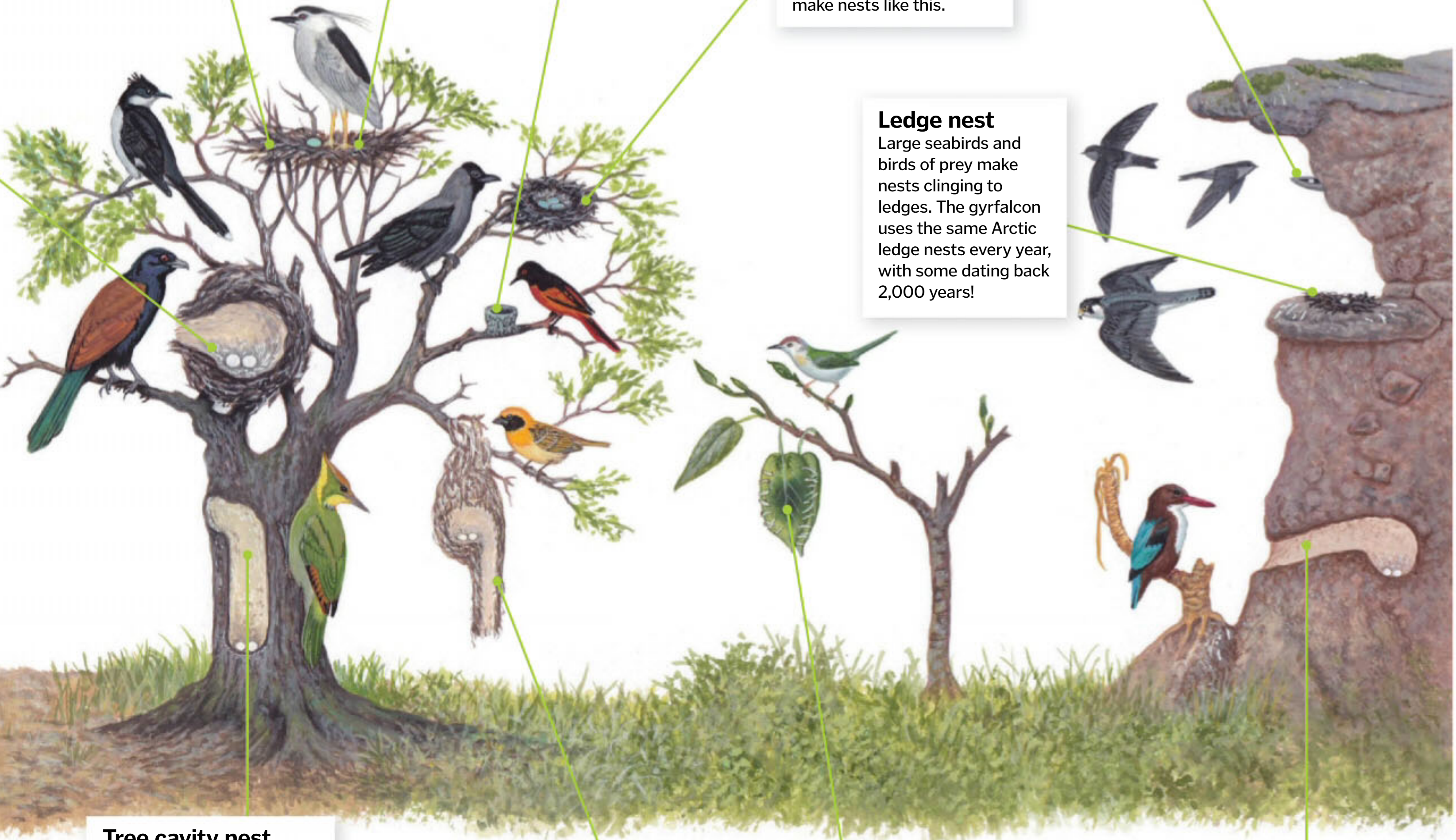
No nest
Some birds, such as emperor and king penguins, make no nest. Instead, they keep their eggs on their feet and cover them to incubate the chicks.

Floating nest
Water birds, such as the little grebe, build floating platforms using twigs and plants in shallow water, using high reeds for camouflage. Wet vegetation regulates the temperature of their eggs.

Water mound nest
This nest is built of mud and sand, elevating it above the water – the flamingo builds its simple nest in the shallows, high enough to keep the eggs dry.

Albatrosses build mound nests; large heaps of mud with a concave centre for their single egg

Pendant nests hanging from trees show off some amazing architecture by weaver birds



Platform nest
These nests are found at all levels. These typically large structures can get bigger year-on-year as the birds add more material. Builders include ospreys and blue herons.

Brood parasite
Cuckoos and cowbirds are two such species that lay their eggs in another bird's lovingly-built nest, then sit back to let another mother rear their chicks!

Statant cup nest
Built by birds such as robins, these are cup nests supported mostly from the base of the nest, and not attached to the tree by the sides of the cup.

Cup nest
This is the quintessential bird's nest shape – circular with a rounded bottom like a bowl. Many songbirds make nests like this.

Adherent cup nest
This type of cup nest relies on attachment by a sticky and adhesive substance, such as mud or saliva. It's made by birds such as cliff swallows.

Ledge nest
Large seabirds and birds of prey make nests clinging to ledges. The gyrfalcon uses the same Arctic ledge nests every year, with some dating back 2,000 years!

Tree cavity nest
Much like burrows, nests in cavities such as hollow trees provide shelter and temperature control. Some species like kingfishers will hollow out their own.

Pendant nest
These impressive structures hang down from branches in mid-air. Made by birds like orioles and weavers, they are sacs of elegantly woven twigs and grasses.

Foliage-supported cup nest
This is a cup nest built within the leaves of a tree, supported by its attachment to vegetation around the rim of the cup.

Rock cavity nest
As well as cavities in wood, birds like wrens utilise holes and fissures in rocks to nest. The benefits are similar: safety from hunters and a stable microenvironment for chicks.

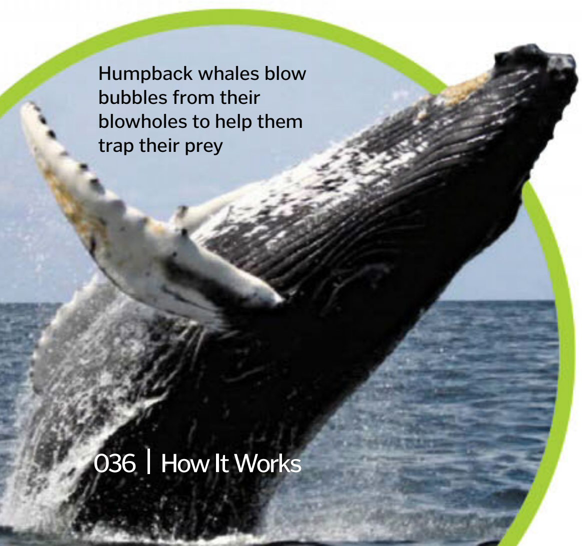
How do baleen whales feed?

Discover what the big-mouthed blue whale does when it's time to eat

You might think the largest animal in the world, the blue whale, would feed on prey of a similar size to it, but its diet actually consists of one of Earth's smallest animals: krill. These tiny crustaceans swim in large groups, making it easy for the blue whale to gulp them down. It can do this thanks to its enormous mouth and something called baleen.

Blue whales are one of 12 baleen whale species, characterised by the baleen plates that hang from their upper jaw. These plates are made from keratin, the same material as fingernails, and form a fringe or curtain at the opening of the mouth. While scooping up large quantities of plankton, krill and small fish, the whales take on gallons of water. The baleen allows them to filter the prey from the water as they spit it back out.

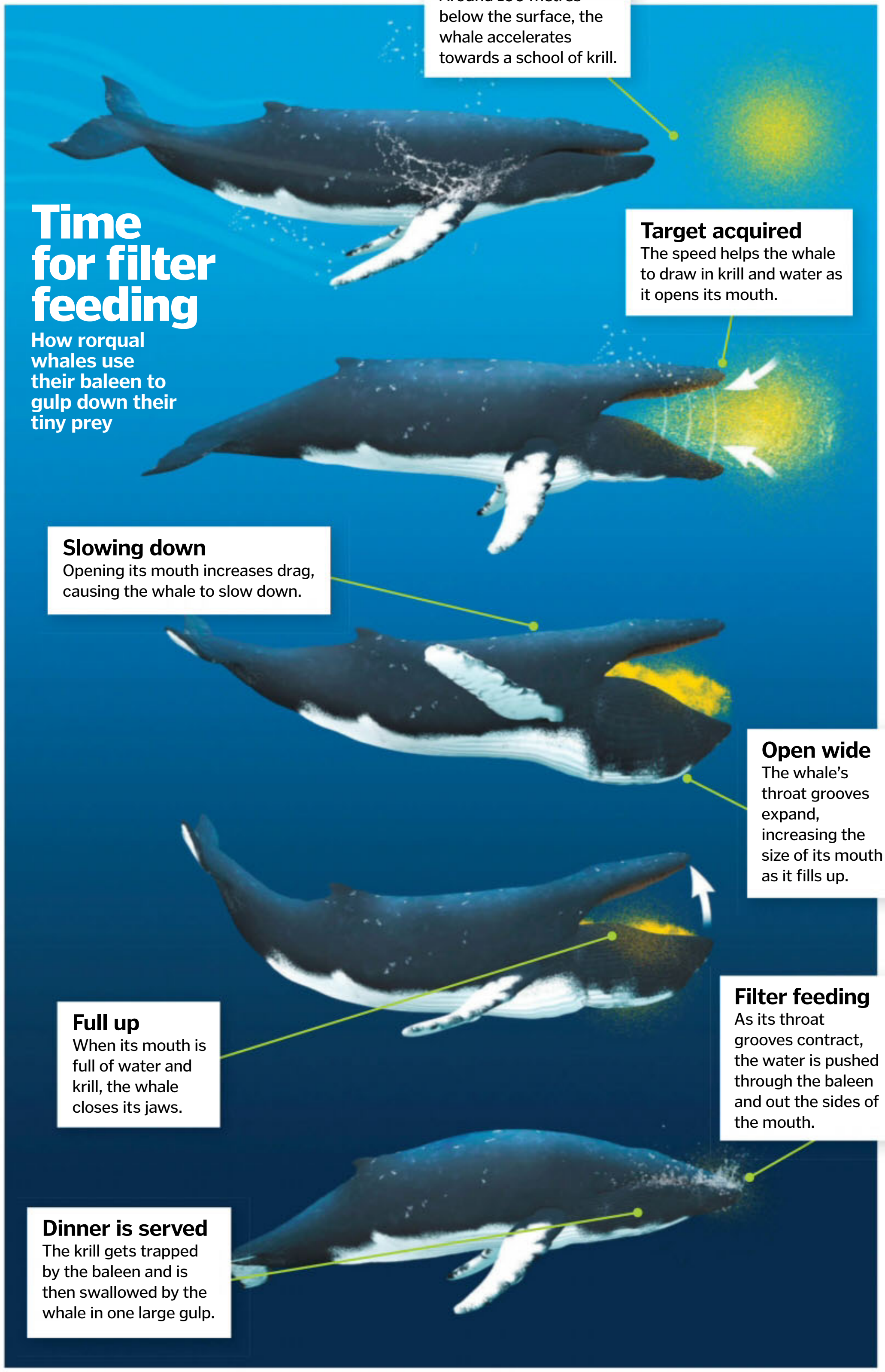
There are four different families of baleen whale, and although they all filter feed, they each do it in a different way. Right whales and pygmy right whales, such as the bowhead whale, feed near the surface, skimming the water with their open mouths. Rorqual whales, such as blue and humpback whales, tend to dive deeper for their prey and have areas of pleated skin called throat grooves that enable them to expand their mouths and take in more food. The final family consists solely of the grey whale, which filters its prey from water and mud that it sucks up from the ocean floor.



Humpback whales blow bubbles from their blowholes to help them trap their prey

Time for filter feeding

How rorqual whales use their baleen to gulp down their tiny prey



Baleen vs toothed whales

There are around 80 different species of whales, dolphins and porpoises, and they can be divided into two groups; baleen and toothed. While baleen whales feed on small prey, toothed whales, such as orcas, hunt for much larger creatures like seals, sea lions and other whales. They use their teeth for grasping and tearing, often swallowing their food whole, and find their prey using echolocation.

Baleen whales are typically larger and slower than their toothed counterparts, with two blowholes rather than one. They also have a much larger tongue and make lower-frequency noises.

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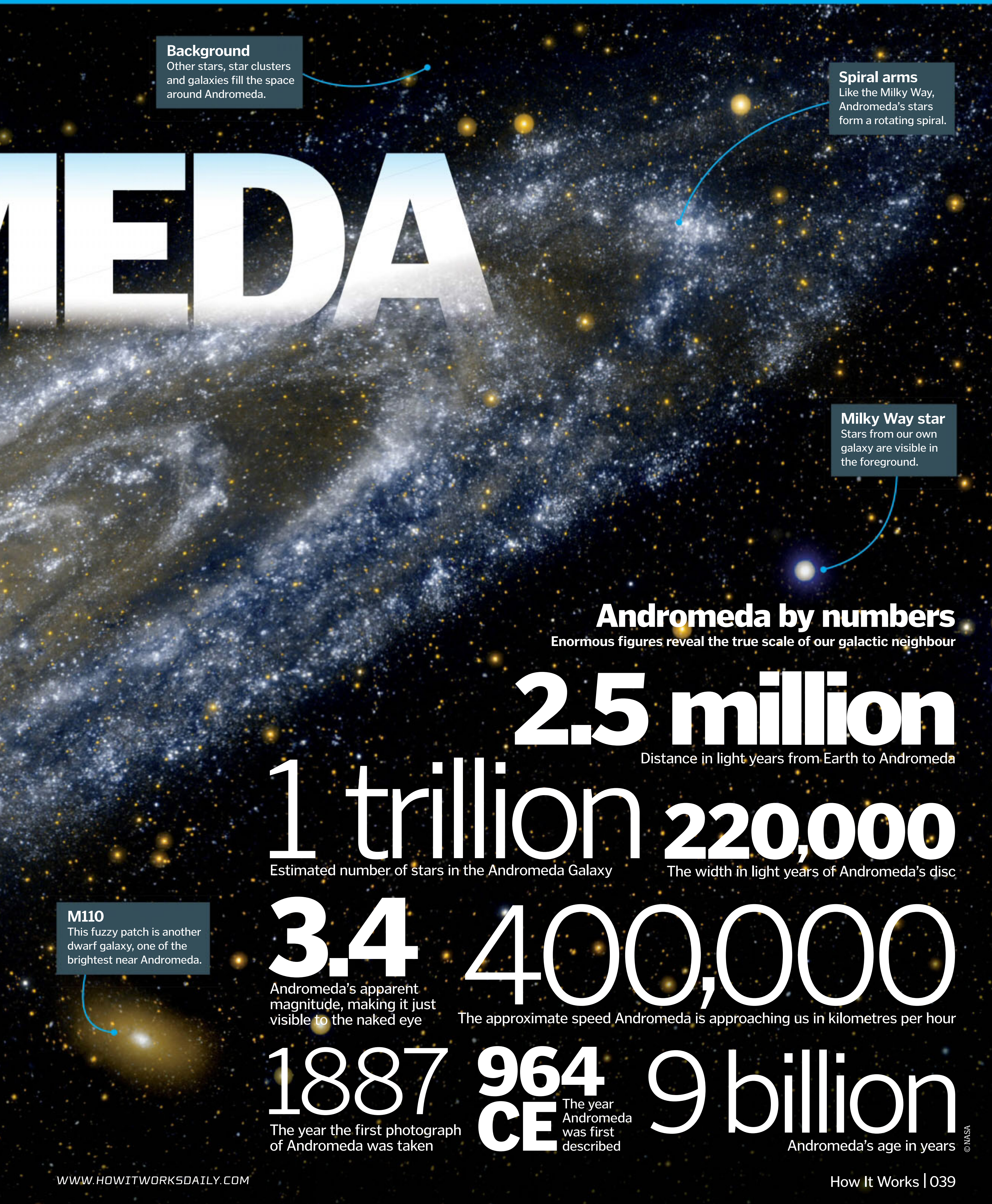
WELCOME TO ANDROM

Our nearest spiral galaxy is on a collision course with the Milky Way

Introducing Andromeda

This impressive spiral galaxy is one of our closest galactic neighbours

"Andromeda is 2.5 million light years from Earth, but it can be spotted without a telescope"



Andromeda by numbers

Enormous figures reveal the true scale of our galactic neighbour

2.5 million
Distance in light years from Earth to Andromeda

1 trillion
Estimated number of stars in the Andromeda Galaxy

220,000
The width in light years of Andromeda's disc

3.4
Andromeda's apparent magnitude, making it just visible to the naked eye

400,000
The approximate speed Andromeda is approaching us in kilometres per hour

1887
The year the first photograph of Andromeda was taken

964 CE
The year Andromeda was first described

9 billion
Andromeda's age in years

All about Andromeda

What this spiral galaxy is teaching us about space

Earth is just a speck. We are one of eight planets orbiting the Sun, which is one of more than 100 billion stars in the Milky Way, which is one of an estimated 2 trillion galaxies in the universe.

When we look up at the night sky, the vast majority of the pricks of light that we can see belong to local stars from our home galaxy, but there are smudges and blurs made by larger objects that are much further away. One of these is the Andromeda Galaxy.

It sits between the constellations of Cassiopeia and Pegasus; a smudge of faint light about the size of the Moon. To the naked eye, it's little more than a haze, but zoom in with a powerful telescope and an enormous spiral galaxy is revealed.

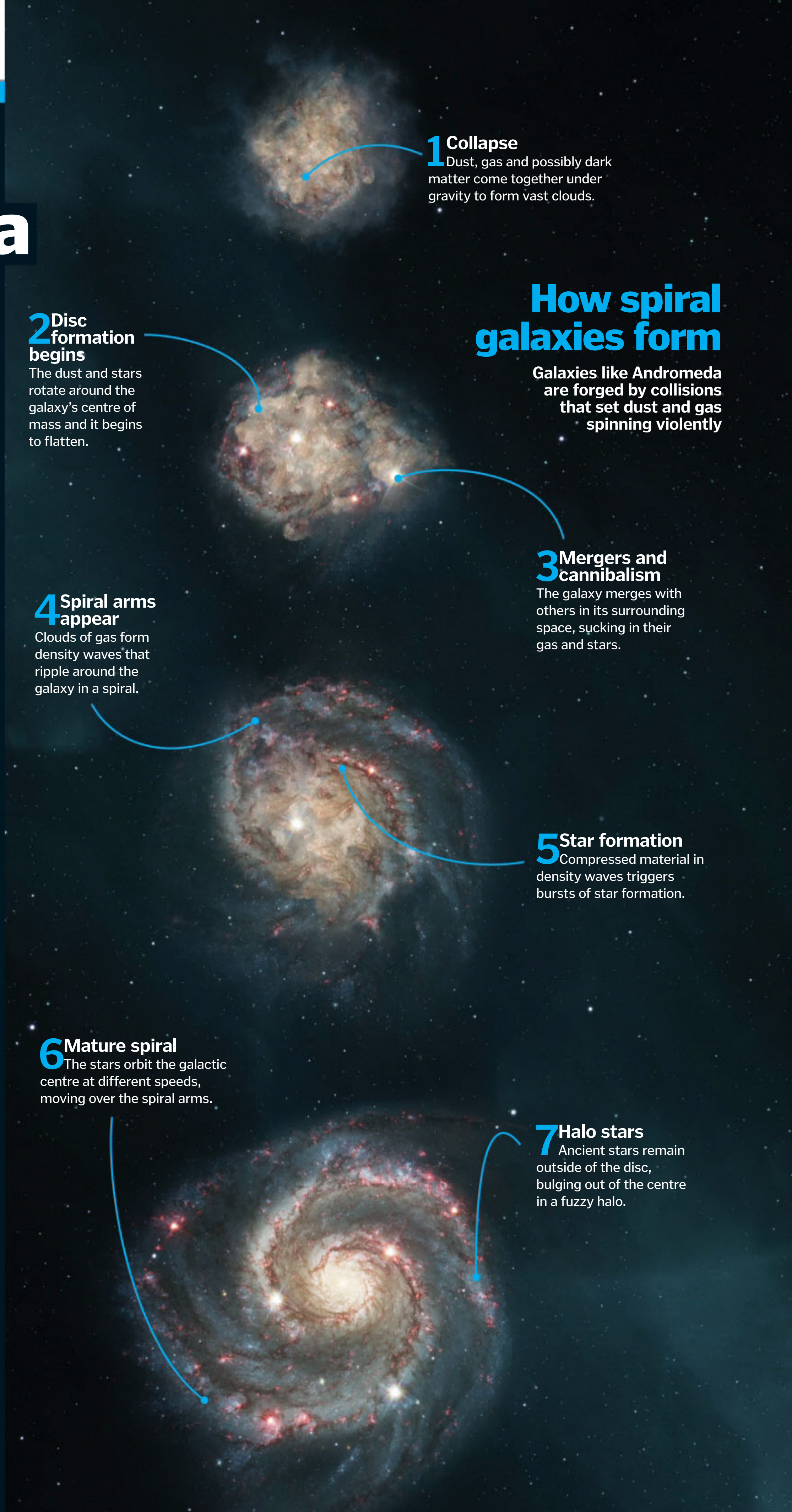
Andromeda is the closest big galaxy to the Milky Way. It's 2.5 million light years from Earth, but it contains so many stars and produces so much light that it can be spotted on a clear, dark night without a telescope. There are other, smaller galaxies in nearby space, but Andromeda is the closest galaxy that looks like our own.

> *"Massive objects, like stars and planets, bend the fabric of space-time"*

It's an enormous spinning disc. Ancient stars cluster in the centre in a halo that conceals a supermassive black hole, and around the edge, stars old and new rotate through lanes of dust and twisting spiral arms. It takes light 220,000 years to travel from one edge of the galaxy to the other, making it more than twice as wide as the galaxy we live in.

It's got more stars too. Andromeda is home to an estimated 1 trillion stars, at least two, if not ten times more than we have in our own galaxy. But, strangely, the Milky Way has more dark matter, so is more massive than Andromeda, even though it doesn't look it. And, like our own galaxy, Andromeda has a supermassive black hole right at its centre, thought to contain the mass of 100 million Suns.

Rather than engulf the galaxy, this black hole acts as the linchpin around which the great disc spins. It is circled by a halo of young, blue stars, and a more distant ring of old red stars, along with up to



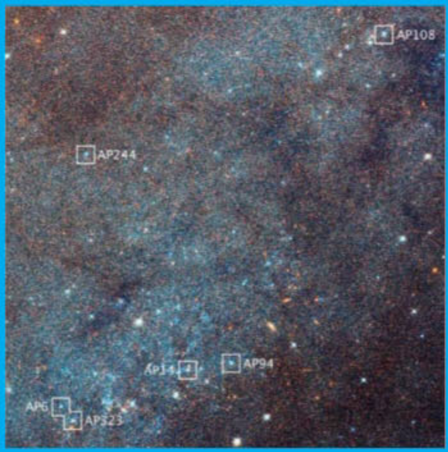
Making stars

We can't see the Milky Way properly from the inside: dust, gas and nearby stars block the view. However, the Andromeda Galaxy is easily observed.

In 2015, the Hubble Space Telescope took nearly 8,000 images of over 100 million stars in Andromeda to find answers about how they formed. The human eye is much better at picking out patterns than computers, so the images were opened up to the public for detailed analysis.

Over the course of just a few weeks, 1.82 million classifications were submitted to a citizen science website called Zooniverse, equivalent to about two years worth of investigation.

Stars come in different sizes and colours, ranging from bright blue supergiants down to small red dwarfs. It turned out that, despite all of the turmoil of space, clusters of stars actually form in similar patterns, with the same proportions of massive young blue stars and older red ones. In the swirl of space there is some order.



Andromeda's clusters contain similar proportions of blue and red stars

Andromeda is home to billions of planets, but they're hard to spot from Earth

Homes away from home

The Sun isn't the only star with planets. In fact, nearly all Sun-like stars have them, and around one-sixth of all stars have planets the size of Earth. Andromeda's stars are no exception. Nestled among the pinprick lights that we can see from Earth are billions of other worlds, and even at this great distance, we can see them. This is thanks to a phenomenon called gravitational lensing.

Massive objects like stars and planets bend the fabric of spacetime – a bit like a bowling ball sat on a rubber sheet. Light travels in straight lines, but because the fabric of space itself is bent, it curves as it passes these enormous obstacles. When stars cross in front of other stars on their way around the centre of a galaxy, the light from the star behind bends on its way towards us. The amount it bends depends on the size of the star, and also on the planets orbiting it.

35 smaller black holes that formed when the largest of these bright objects ran out of fuel.

Andromeda is a window into the universe, allowing us to study how galaxies like our own form and change over time, and telescopes on the ground and in space are often pointed in its direction in order to gather more clues. Some examine the visible light emitted by its stars; others probe ultraviolet light released by hot, energetic stars; and still more explore infrared to learn about the dark, dusty matter that's normally hidden in the glare.

Andromeda has lots of secrets. At around 9 billion years old, it is younger than the Milky Way by about 4 billion years. It is thought to have formed from the merger of two galaxies, one around the size of our own, and one about three-times smaller. Their gravitational pulls would have become entangled, pulling the stars of each together until they met in a dramatic collision. The impact set the whole object spinning, and as the dust, gas and stars sped around the centre, they would have spread out to form the thin disc shape that we can see today.

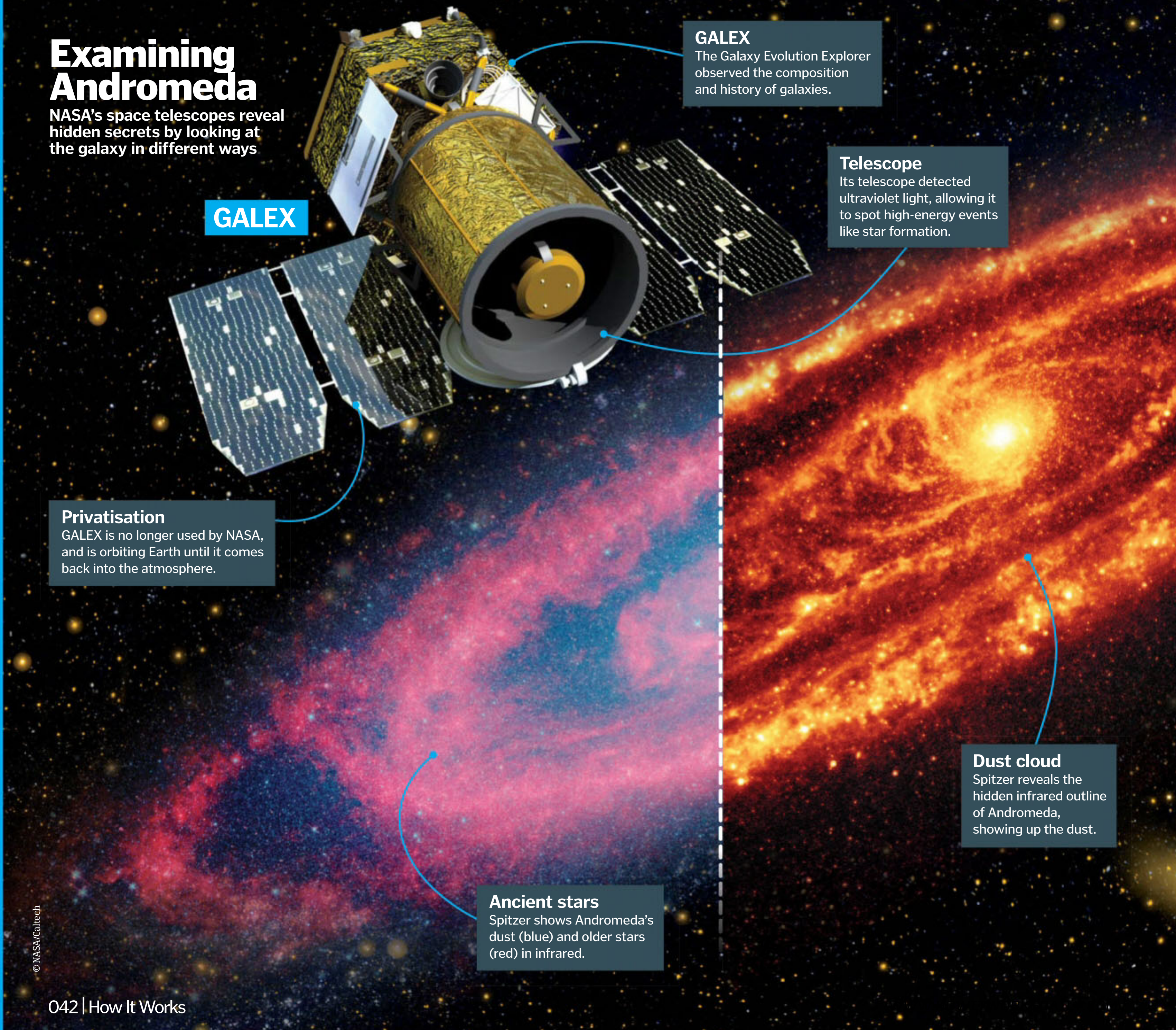
Strangely, Andromeda is also orbited by a selection of dwarf galaxies, which from Earth appear to be trailing around the galaxy in a line. This unusual formation is proving challenging for scientists to explain, but could have something to do with its turbulent past.

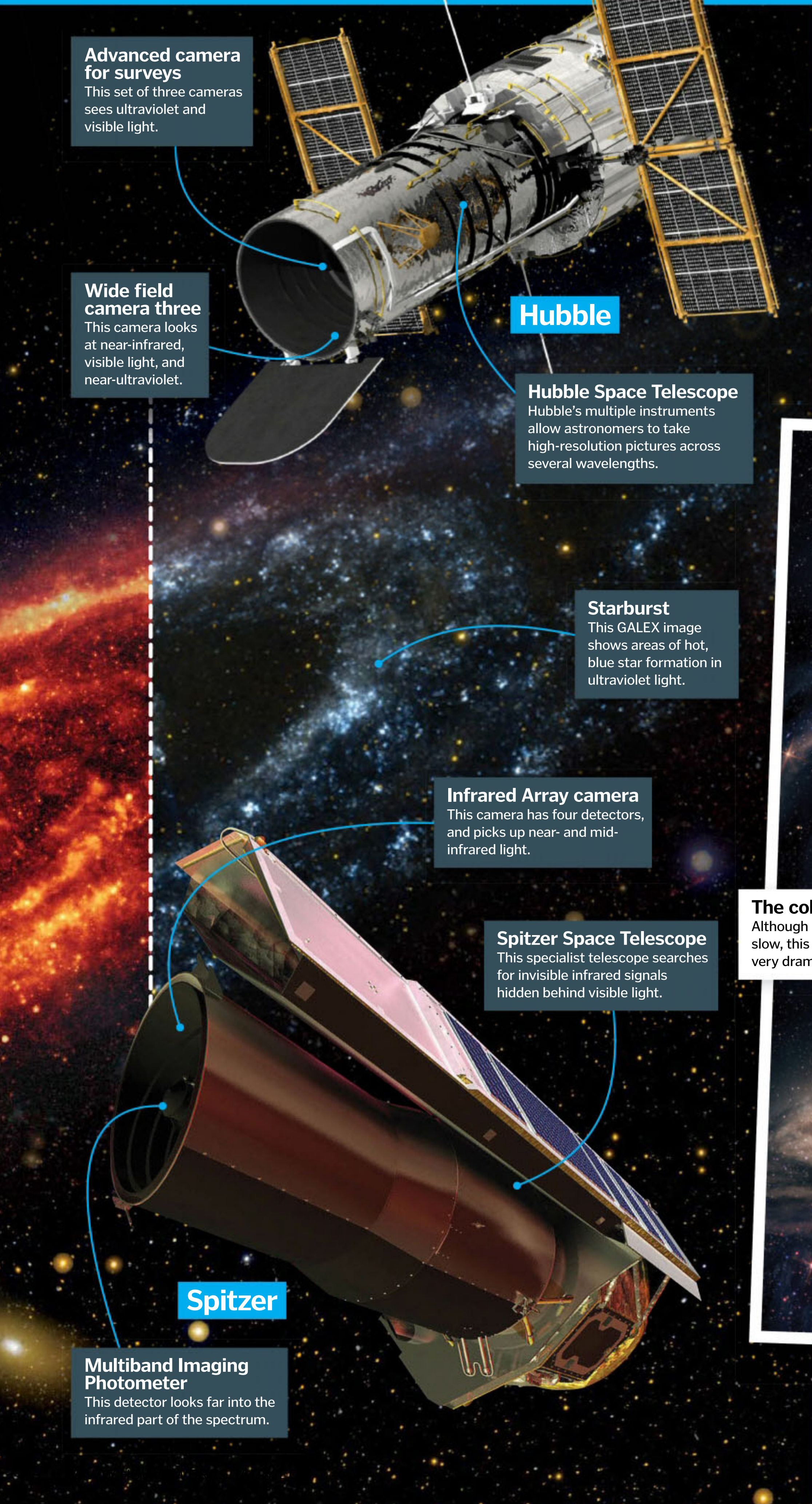
And that wasn't the last collision that Andromeda experienced. Infrared images have revealed that the structure of the galaxy is distorted. Beneath the bright lights of the stars, there are off-centre dust rings, and visible ripples in its galactic halo. Astronomers think that these quirks are the result of a head-on crash with a smaller galaxy, M32. As the little galaxy collided with the heart of Andromeda, it warped the big spiral disc, and set off rings of star formation that can still be seen today.

As for the future, Andromeda is set for another huge collision that will change its shape yet again. But this time, the galaxy it will hit is much closer to home: it's heading straight for the Milky Way. But until they meet in approximately 4 billion years, we'll have lots of opportunities to study it and to learn more about the formation of the universe.

Examining Andromeda

NASA's space telescopes reveal hidden secrets by looking at the galaxy in different ways



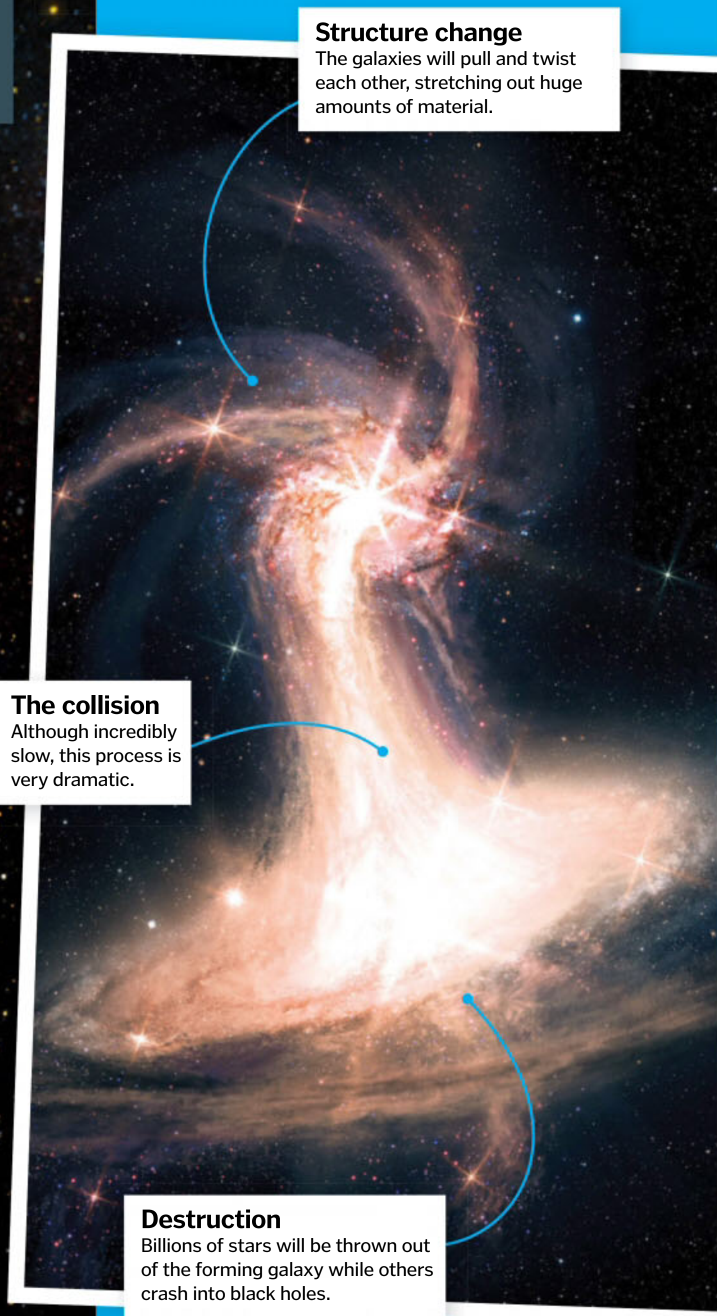


Galactic collision

Andromeda and the Milky Way are billions of light years apart, but their enormous gravitational pulls have become tangled together, and they are racing towards each other at over 400,000 kilometres per hour. It will be another 4 billion years before they meet, but when they do, both galaxies will be transformed, and in their place, a massive elliptical galaxy will form.

Thankfully, Earth is unlikely to be harmed. The stars in each galaxy are so far apart that they should just dash past each other as the galaxies merge. The Sun is likely to end up in a different part of the new galaxy, and the sky will be filled with new stars.

But after all that excitement, we humans might not even get to see the merger through. It will take 2 billion years for two galaxies to combine completely, and by that time, our Sun will be dangerously low on the fuel that allows life to flourish on Earth.



"It'll be another 4 billion years before they meet"

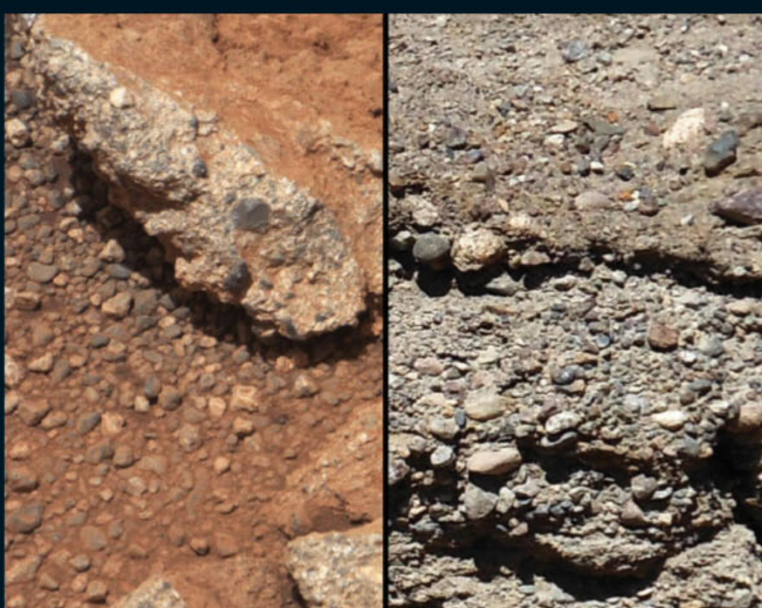
Mars missions

Why is the Red Planet such a popular destination for space probes?

Sending probes to other worlds is no mean feat, yet since the 1960s we have launched more than 40 missions to Mars. While the majority of these missions were failures, that hasn't stopped space agencies from trying. Thanks to technological advancements and years of trial and error, we're getting better at it. There are currently six probes orbiting Mars and two rovers patrolling its surface, with more missions in the pipeline.

But why do we keep going back to Mars? It's an inhospitable planet, with a tenuous atmosphere, maybe no magnetic field, and surface temperatures regularly well below freezing. Despite this, it does have similarities to our own planet: it has a near 24-hour day and is tilted on its axis so experiences seasons. The most interesting thing, though, is that water may still exist there. Images of Mars' surface taken by orbiters show the remnants of seas, lakes and riverbeds, indicating that the Red Planet was once habitable.

In 2015, the Curiosity rover discovered evidence that briny water does still flow just beneath the Martian surface, which potentially means that some form of life could still exist there. Future missions will continue to search for these signs of life and uncover more about Mars' habitable past.



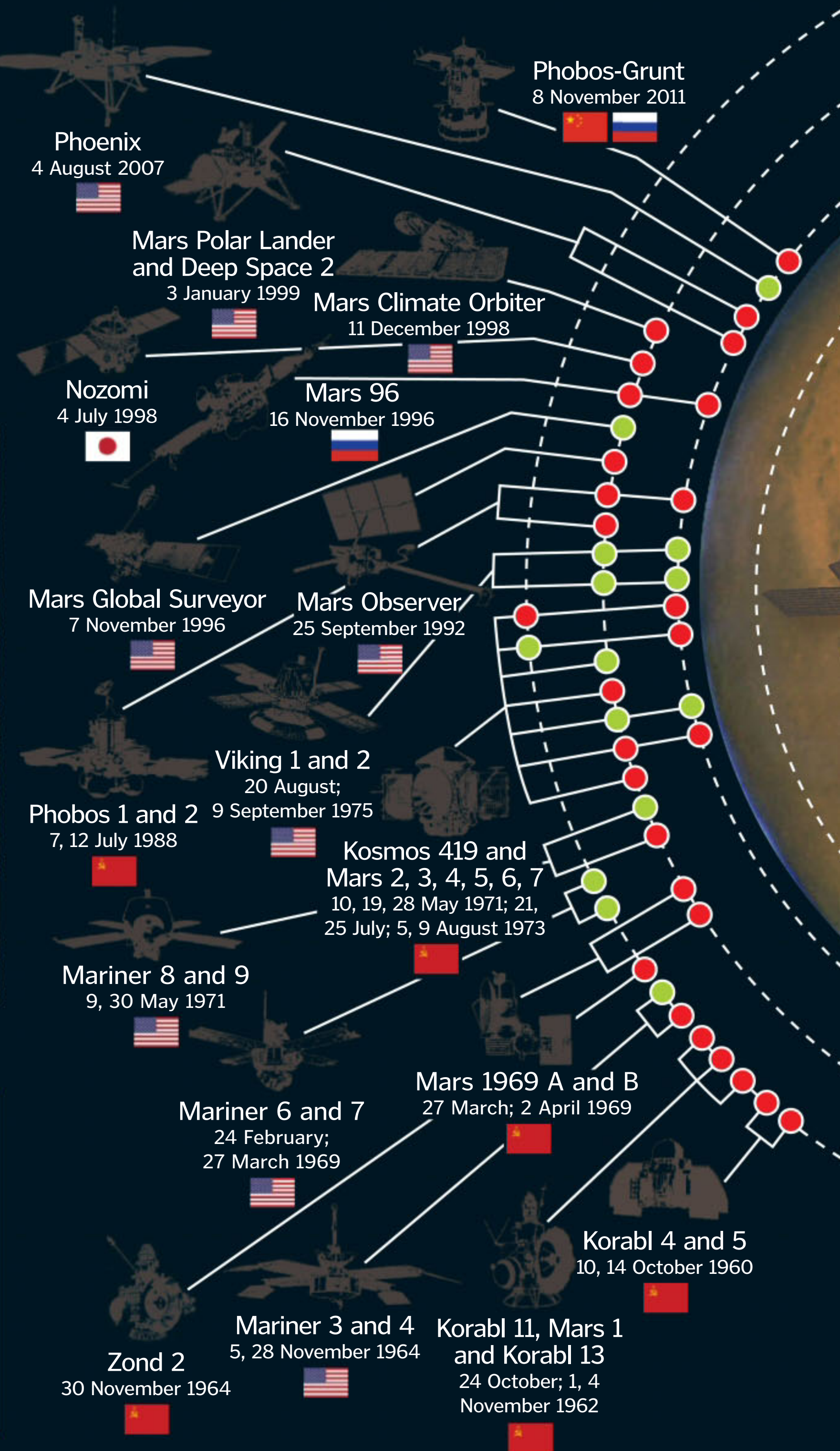
Gravel deposits from an ancient streambed on Mars (left) greatly resemble those created by water erosion on Earth (right)

Missions by country

- USA: 21 (15 successful)
- Russia*: 19 (3 successful)
- Japan: 1 (failure)
- ESA: 1 (partly successful)
- China†: 1 (failure)
- India: 1 (successful)
- UAE: (1 mission planned)

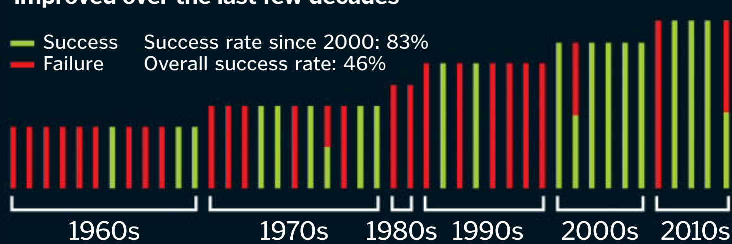
* includes both USSR ( ) and Russia
† joint mission with Russia

PAST

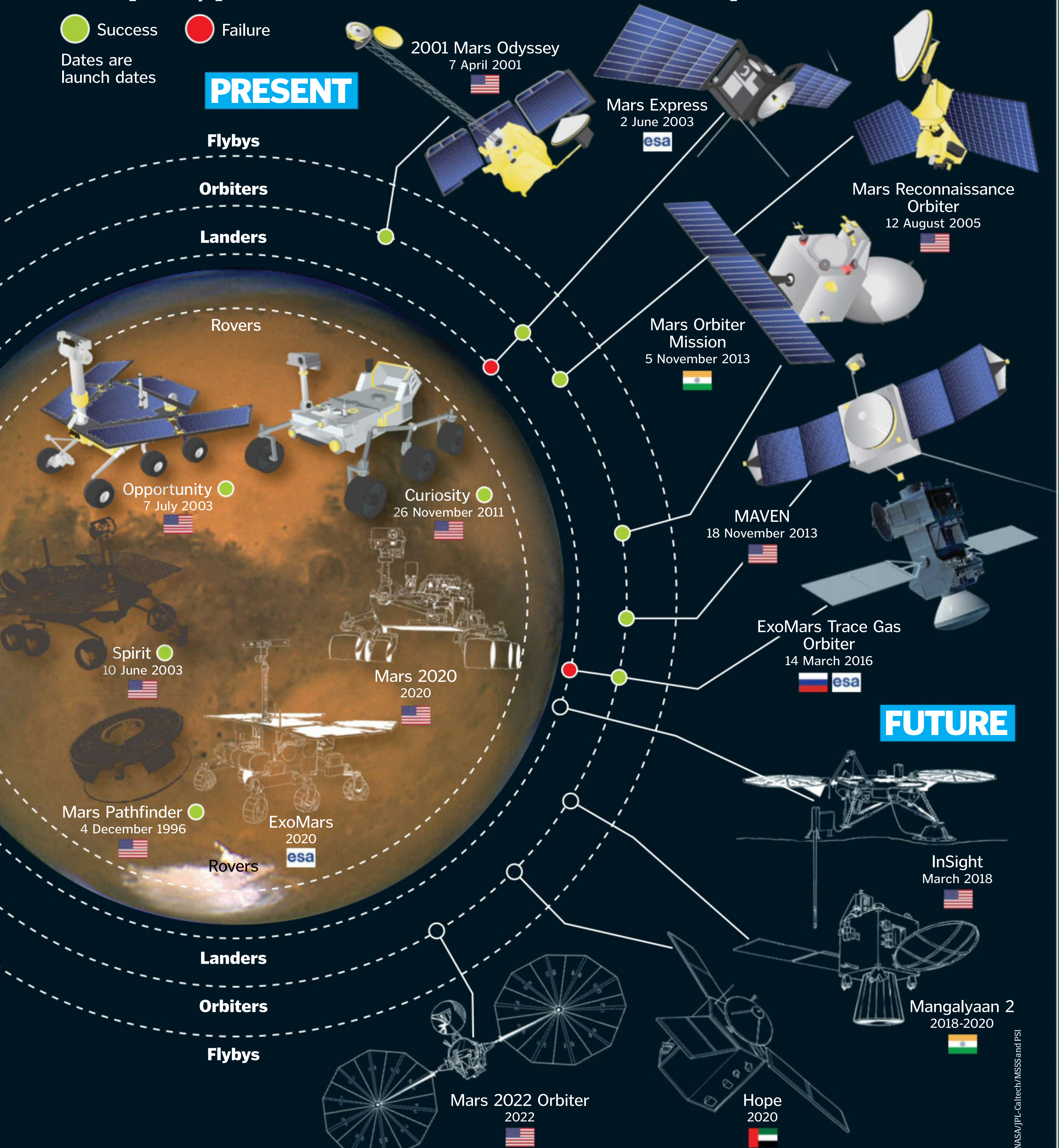


Successes and failures

Our success rate with Martian missions has greatly improved over the last few decades



The past, present and future of Martian exploration



Mauna Kea experiences a high proportion of clear skies, which is ideal for astronomical observations

Mauna Kea Observatory

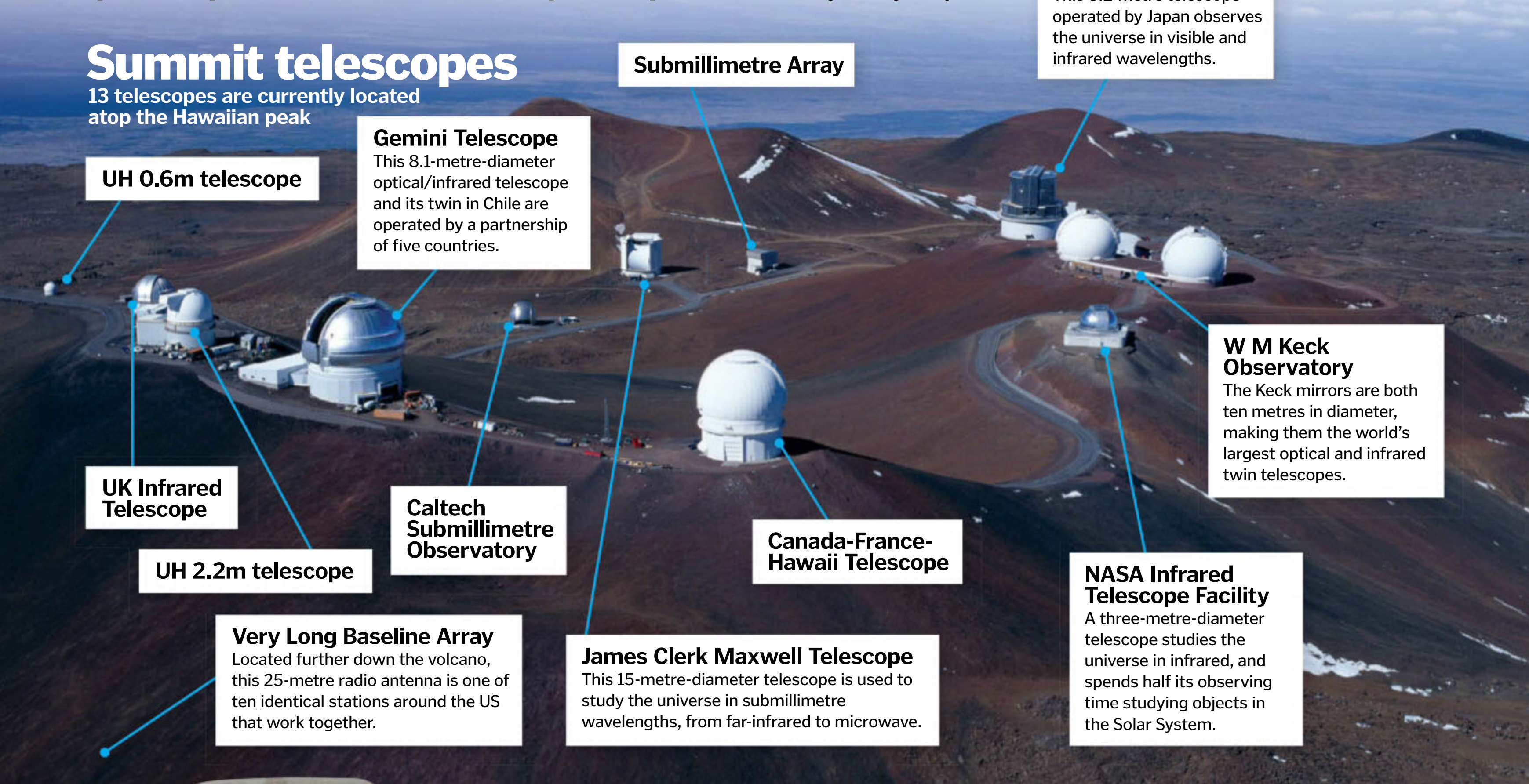
Why are so many telescopes built at the top of a dormant volcano?

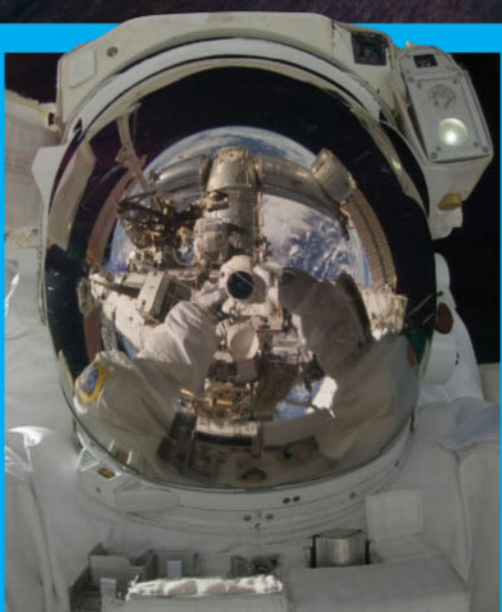
The summit of Mauna Kea on the island of Hawaii is home to the largest astronomical observatory in the world. The combined capabilities of the 13 telescopes located on this volcano are 60-times greater than the light-gathering power of NASA's Hubble Space Telescope.

This location is ideal for astronomy as it rises approximately 4,205 metres above sea level, so the summit is above 40 per cent of the atmosphere, which can interfere with observations. The atmospheric conditions at the site are also very dry, cloud-free, and free from pollutants, perfect for observing the night sky.

Summit telescopes

13 telescopes are currently located atop the Hawaiian peak





Astronauts can pull down their gold visors during EVAs to protect their eyes against intense sunlight

Sun visors

How do spacesuit helmets protect against harmful rays?

When performing spacewalks or extravehicular activities (EVAs), a space suit is an astronaut's lifeline, protecting them against extreme temperatures, pressures and radiation. One important aspect of this is the Sun visor in the astronaut's helmet.

Outside the Earth's protective atmosphere, sunlight is even brighter, so astronauts must avoid looking at it just as we do on Earth. In addition to their primary, transparent visor, astronauts have a gold-coated outer visor, which can be pulled down when conditions are too bright, much like putting on a pair of sunglasses. The gold layer is very effective at reflecting infrared light, while the primary visor reflects the majority of ultraviolet wavelengths, both of which can cause retina damage. This is particularly important during delicate operations such as docking or EVA maintenance, where being subjected to blinding sunlight could lead to dangerous mistakes.

The visors also help protect astronauts against extreme temperatures. The gold coating reflects light and heat from its surface, while the primary visor includes an inner coating that helps retain heat emitted by the astronaut to help maintain a comfortable temperature. To prevent their visors clouding up and obscuring their view, astronauts also apply an anti-fog spray to the inside of their visors when suiting up.

DID YOU KNOW? *Belgian Georges Lemaître first proposed the idea of Hubble's law in an article on general relativity in 1927*

Expansion of the universe

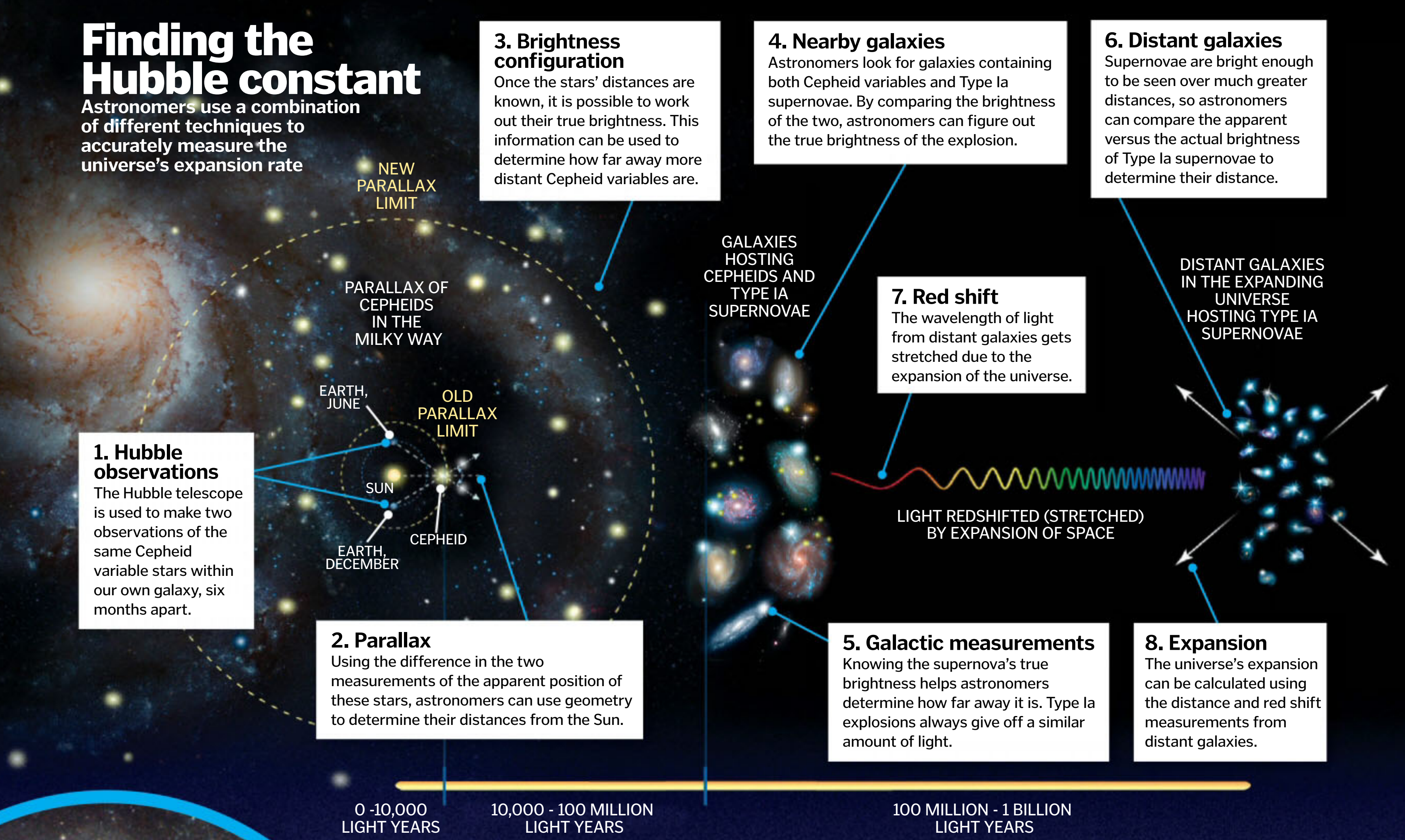
How do scientists calculate how fast the universe is expanding?

In 1929, American astronomer Edwin Hubble announced a truly ground-breaking discovery: the universe was expanding. By observing the light from distant galaxies, Hubble found that their wavelengths were stretched out (known as red shift, as the light is shifted towards the red end of the light spectrum), and the further away the galaxies were, the more red shifted the light was. This observation only made sense if the universe was expanding.

The extent of a galaxy's red shift indicates the speed at which it is moving. Hubble found that a galaxy's distance and speed, and therefore the rate of the expansion of the universe, were directly linked by a constant value, which is known as the Hubble constant.

In 1929, the constant's value was 500 kilometres per second per megaparsec (one megaparsec is approximately 3.26 million light years), but this figure was based on limited data. Astronomers later discovered that Hubble was incorrect by approximately a factor of ten; but over the years – with improved data and techniques – they have been able to refine the Hubble constant's value.

In 2016, scientists were able to make the most precise estimate yet: 73.2 kilometres per second per megaparsec. This more accurate data led to the discovery that the universe is in fact expanding between five and nine per cent faster than previously expected.



A Hubble Space Telescope image of one of the galaxies measured in the June 2016 survey to estimate the expansion of the universe

What are Cepheid variables?

Cepheid variables are a group of stars that are very large and luminous. The majority of stars become Cepheid variables after the red giant phase towards the end of their lifespans, and pulse as they expand and contract, glowing brightly and fading over regular intervals.

The period of a Cepheid star's brightening and dimming pattern can last from one to 100 days, and is directly related to its true brightness. By comparing the star's true brightness to its apparent brightness (how bright it seems from Earth), astronomers can calculate how far away it is. Cepheid variables have been very useful distance measuring tools since their period-luminosity relationship was discovered by American astronomer Henrietta Leavitt in 1912.

PERSONAL TRANSPORT GADGETS

COULD THESE HI-TECH TRAVEL GADGETS BE THE FUTURE OF GETTING AROUND?

Walking has never been enough for humans. From roller blades to helicopters, we've always been looking for more efficient – or more fun – ways to get around. Sadly, 2015 passed by without Marty McFly's hoverboard from *Back To The Future 2* appearing, and we're still some way off flying cars. Even so, personal transport certainly has changed in the last few years.

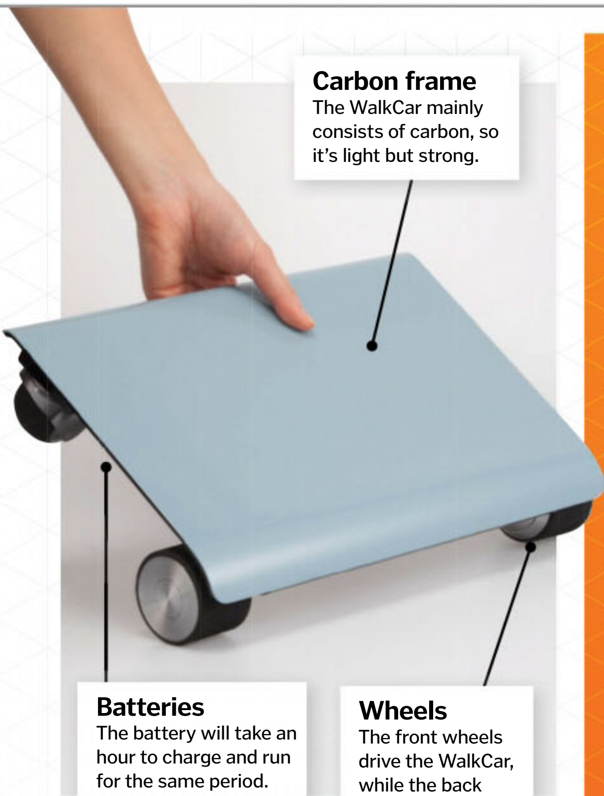
Right now, jumping on a train or riding a bike might be the most obvious way to get to work or school, but modern gadgets are doing their best to change that. Whether it's the electric gizmos that whisk you away with a lean of your body, or more advanced tech like personal drones, there's no doubt that transport tech is moving just as quickly as other fields.

We've all seen the 'hoverboards' that were all the rage in 2016. No, they didn't actually hover, and no, they weren't really all that great. But the tech they used is being advanced in 2017, and soon a portable self-balancing scooter you can slip into your bag might be the best way to travel.

For trips where you want some speed, an electric skateboard could help you whizz through the city, scale hills easily, or just take you on a fun journey with friends. Or, if you're going a little further, you might soon be able to tap your smartphone and order a drone to come and pick you up. Climb in, tap the screen inside, and you can sit back and relax while the drone autonomously carries you where you need to go.

However, it's still a few years away, and even when it is ready for the mainstream it will need to comply with all kinds of safety rules to become legal. Still, with driverless cars just a few years from becoming standard, it's only a matter of time until the technology takes flight.

We might not have real hoverboards just yet, but personal transport tech is getting smarter, and with cities always changing and advancing, these innovative gadgets could soon have their own space on the road and in the skies. Read on to discover some of the coolest gadgets around.

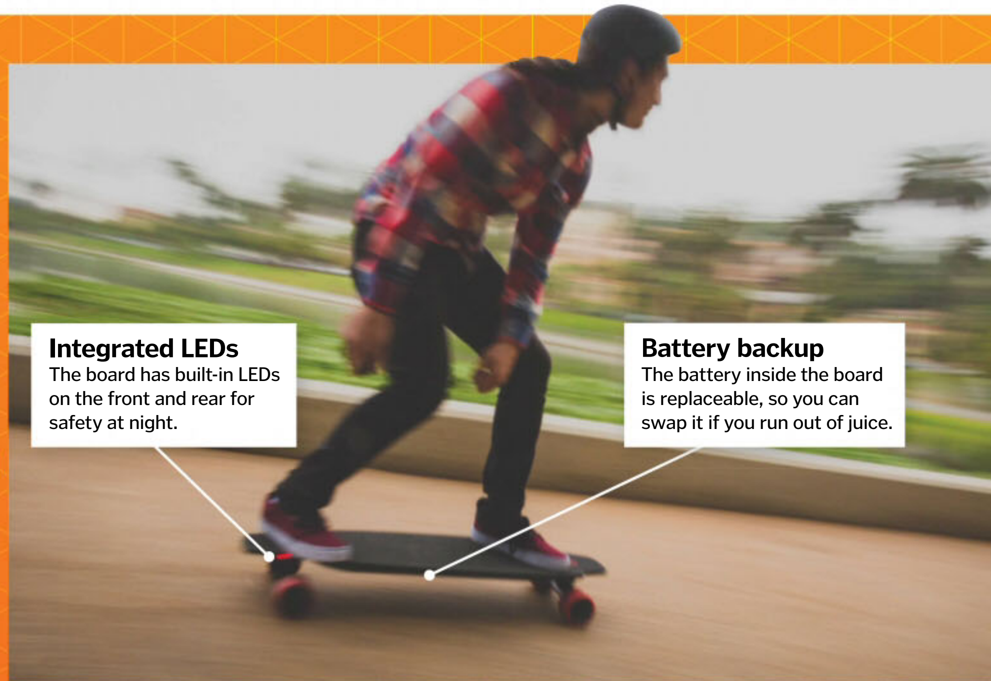


Ride with the WalkCar

Segways might have become more mainstream – especially in the US – but they are still big, bulky devices that can be awkward to store. Thankfully, that might be about to change, as Tokyo-based company CocoaMotors have created a 'portable transporter' that you can slip into a bag.

The WalkCar looks more like a laptop than a mode of personal transportation, but don't let looks fool you. This 33-centimetre segway will charge in around an hour, giving you an hour of riding time at a respectable 16 kilometres per hour. It's made of carbon, so weighs just 2.8 kilograms, making it light enough to carry around when you're not speeding through town.

This little thing can go at about running speed, and slips into a bag like a laptop



The Inboard M1 skateboard

If you like the look of the WalkCar, but prefer a traditional skateboard, then the M1 from Inboard may be the perfect solution. This device takes electric skateboards to a new level by including new motors, called manta drives, inside the wheels themselves. This means there are no belts or external motors pushing the wheels along, and when the batteries run out or you just want to glide downhill, the M1 feels like any other skateboard.

The M1 also features a removable battery, meaning you can carry spares and switch them in when you've coasted the 11-16 kilometres that a single charge offers. The top speed of the M1 is an impressive 38.6 kilometres per hour, and it can manage inclines up to 15 degrees, meaning you won't have to hop off in steeper areas. There's even a wireless remote that controls the board's speed and braking, or you can use a smartphone app if you prefer.

Inside the Inboard M1

The tech that powers this smart skateboard

The Ryno uses a gyroscopic balance system to stay upright when you sit on it

Taking apart the Ryno

How does this electric microcycle provide a speedy, safe and comfortable ride?

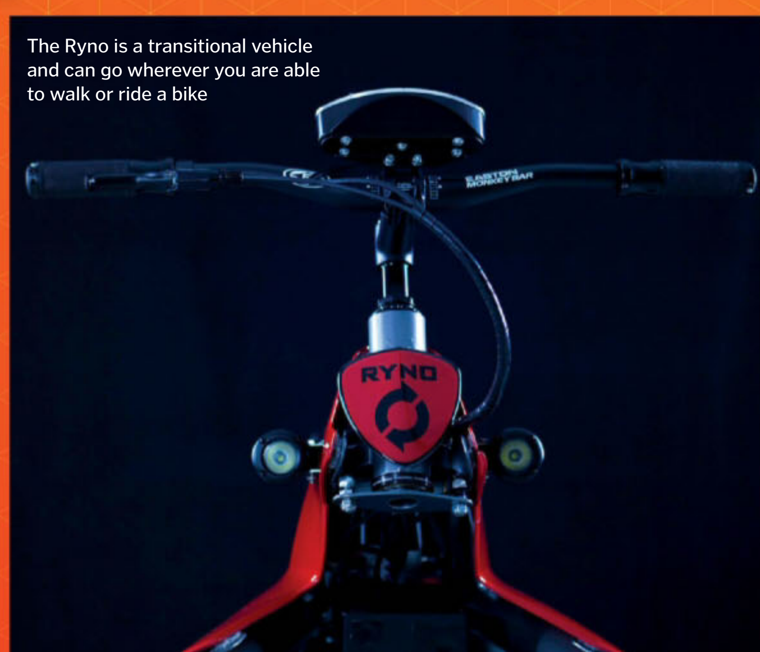
The microcycle

The Ryno one-wheeled microcycle expands on what segways like the Uniwheel have been doing for a few years now, taking a single wheel and gyroscopic controls and bringing it to a comfortable everyday device.

The Ryno looks like a motorbike that's lost a fight with a scrapyard crusher, but every part is carefully considered. The motor and the batteries are stored inside the wheel, giving the whole vehicle a low centre of gravity, leaving the rest of the microcycle to focus on comfort.

You accelerate by leaning forwards, just like a segway, but in the Ryno's case shock absorbers and handlebars will help keep you comfortable and safe. With a top speed of 16 kilometres per hour and a battery that provides a maximum range of 24 kilometres, this could be the next big obsession for motorbike aficionados.

The company promises that the Ryno is intuitive to ride, and in just a few hours you'll be riding instinctively



The Ryno is a transitional vehicle and can go wherever you are able to walk or ride a bike

The Uniwheel

It might look tougher to master than a unicycle, but the Uniwheel's combination of segway-like gyroscopic control and smart design makes it one of the most unique devices on the market. Designed and engineered in the UK, the Uniwheel offers customisable colours, replaceable bumpers and a swappable battery that makes this the perfect mode of transport for getting around fast. The top speed is around 22 kilometres per hour and the Uniwheel has a range of around 11 kilometres – this will easily get you to school or work, and back again. Weighing just 10.8 kilograms, the Uniwheel is surprisingly portable when you're not using it.

Many rideables include self-balancing technology to help you stay stable

The Uniwheel is a compact and lightweight self-balancing electric wheel designed in the UK

Uniwheel deconstructed

How the Uniwheel works

Battery packs
The battery packs are designed to be easily swappable, to extend the range of the Uniwheel infinitely.

Replaceable covers
The battery covers come in many colours, so you can customise your Uniwheel with your own style.

Bumpers required
Electric wheels can become scuffed as you use them, so these bumpers are replaceable.

Foot plates
Getting used to the Uniwheel's unique balance is tough at first but it soon becomes second nature.

Motor
The 1,500-watt motor can go up to 22 kilometres per hour, equivalent to a really fast running speed.

"Designed in the UK, the Uniwheel offers customisable colours and swappable batteries"

The flying car

Meet the Ehang - your personal taxi drone

The dream of having your very own flying car might not have come true just yet, but if Chinese company Ehang has anything to do with it, you won't be waiting much longer. Its Ehang 184 is a personal drone that will fly you around autonomously – all you have to do is tell it where you want to go, sit back, and relax.

The drone is designed for one person, and in theory will work a little like an Uber. Open an app and order an Ehang to see a drone land nearby. You can climb in, tap on the tablet in the cockpit, and the drone will take off. Don't expect it to take you across the country, though – the 184 will be designed for short trips lasting around 20 minutes in total before needing to recharge. While you fly, a tablet in the cockpit will let you monitor your journey, and enjoy entertainment, just like on an airplane.

Ehang claims that the drone will take just a few hours to recharge, and travel at an average of 100 kilometres per hour, but there are several hurdles to overcome before these lofty ambitions can be met. One of the biggest will be to work with aviation authorities to define a new category of flying licence , meaning it will need to pass strict safety tests. Still, it means we're edging closer to a future with flying cars. We can't wait!

The drone is less than two metres tall, and the arms can be folded for storage

Inside the Ehang 184

How will this autonomous personal drone actually work?

Charge it up
The company claims that the drone will charge in two to four hours, and offer over 20 minutes of flight time from a charge.

Eight motors
To carry the weight of the passenger, the eight motors will provide 106 kilowatts of energy.

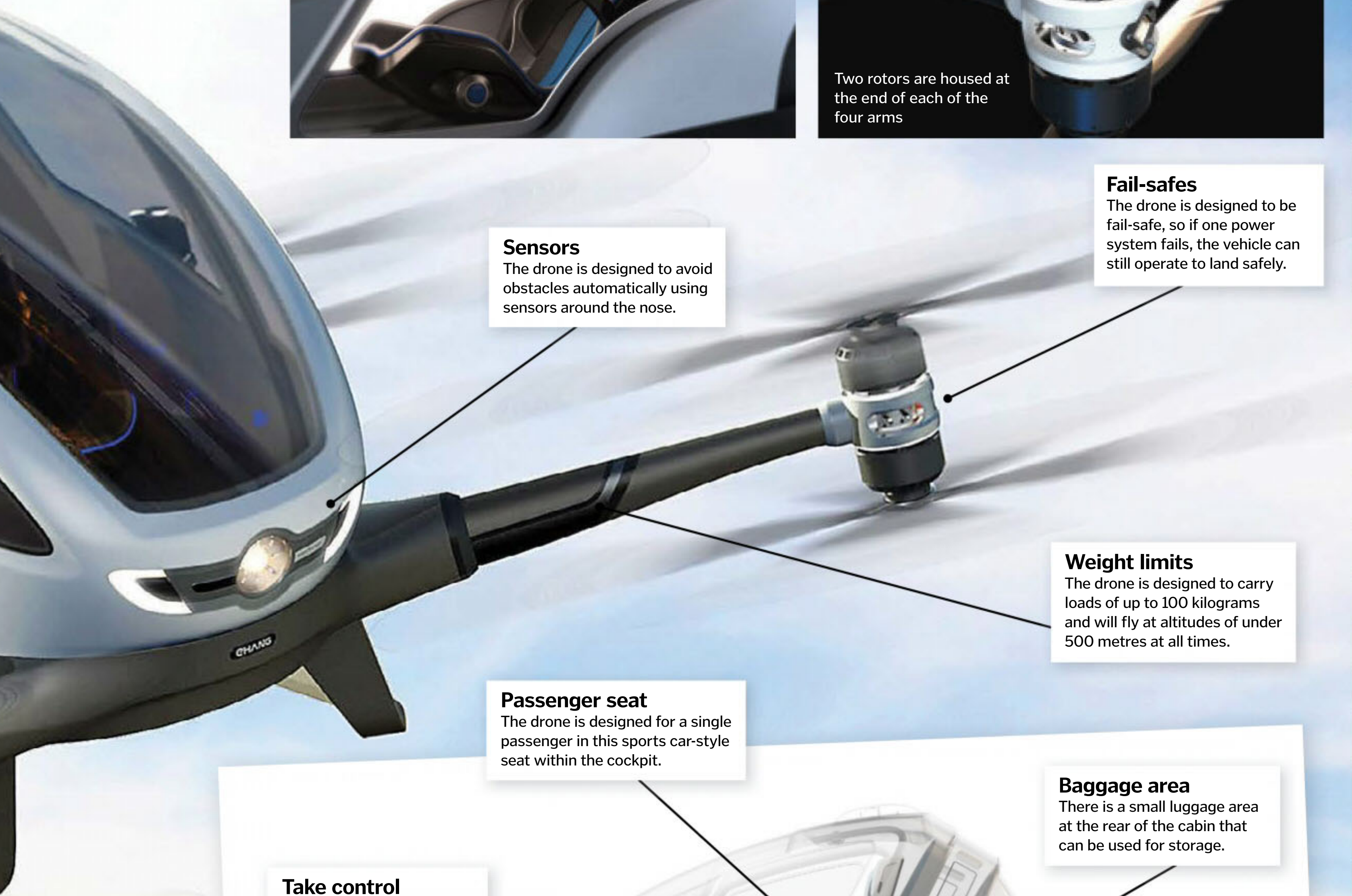
Power banks
The power banks and computer systems are stored underneath the drone, under the passenger's seat.

"Open an app, order an Ehang and a drone will land nearby"

You will be able to monitor your route, the climate controls and more from the built-in tablet

The custom-designed interior will feature a tablet interface

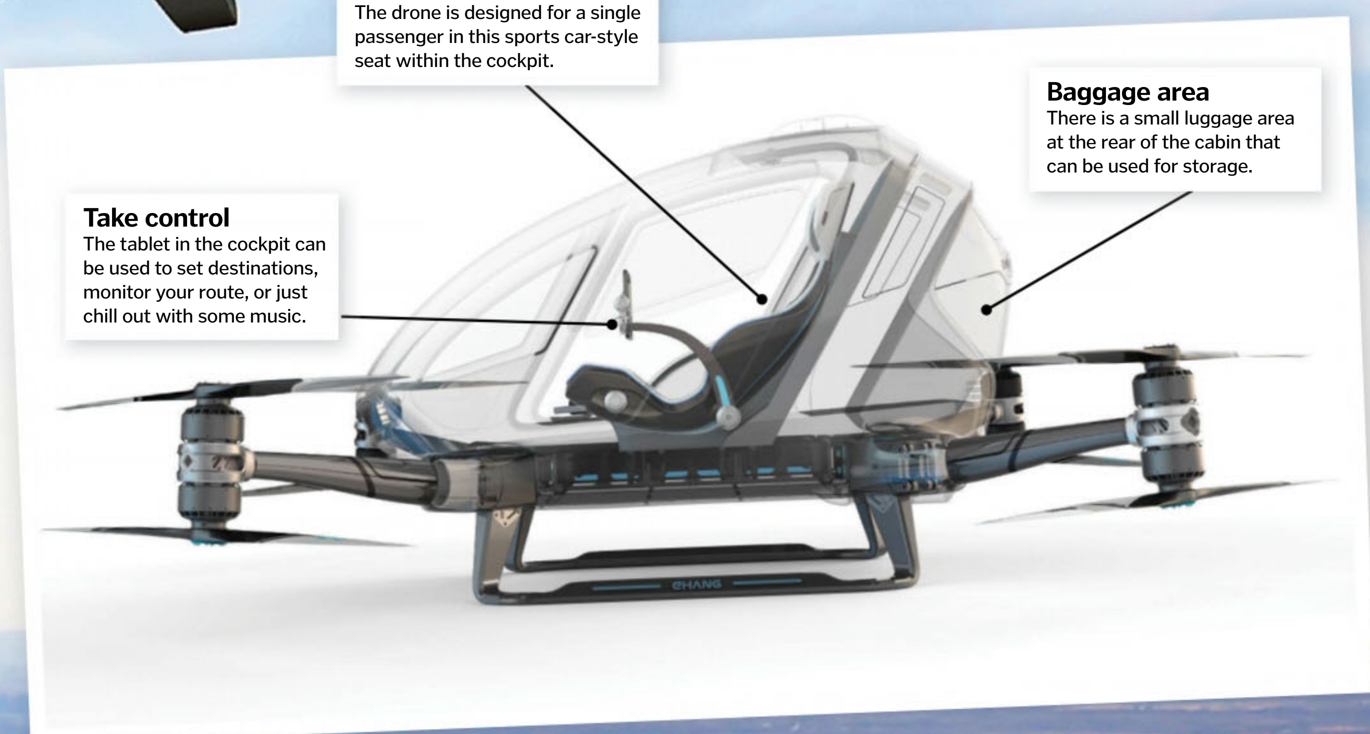
Two rotors are housed at the end of each of the four arms



Fail-safes
The drone is designed to be fail-safe, so if one power system fails, the vehicle can still operate to land safely.

Sensors
The drone is designed to avoid obstacles automatically using sensors around the nose.

Weight limits
The drone is designed to carry loads of up to 100 kilograms and will fly at altitudes of under 500 metres at all times.



Passenger seat
The drone is designed for a single passenger in this sports car-style seat within the cockpit.

Baggage area
There is a small luggage area at the rear of the cabin that can be used for storage.

Take control
The tablet in the cockpit can be used to set destinations, monitor your route, or just chill out with some music.

Narrowboats

Discover why these boats got their name and how they fuelled the growth of British industry

Although narrowboats today are often seen on rivers, they were originally specifically designed to be able to navigate the constructed channels of the British canal network.

Some canals have locks that are only a couple of metres wide. The only vessels that can traverse these are, literally, 'narrow boats'. This limitation, however, originally meant that working narrowboats had to be long so they could carry several tons of cargo. The result is their distinctive elongated shape.

The way canals work imposes limits on how much cargo can feasibly fit on a narrowboat. A boat can't be longer than the maximum length that will fit between lock gates because these must be closed to allow the boat to overcome changes in elevation.

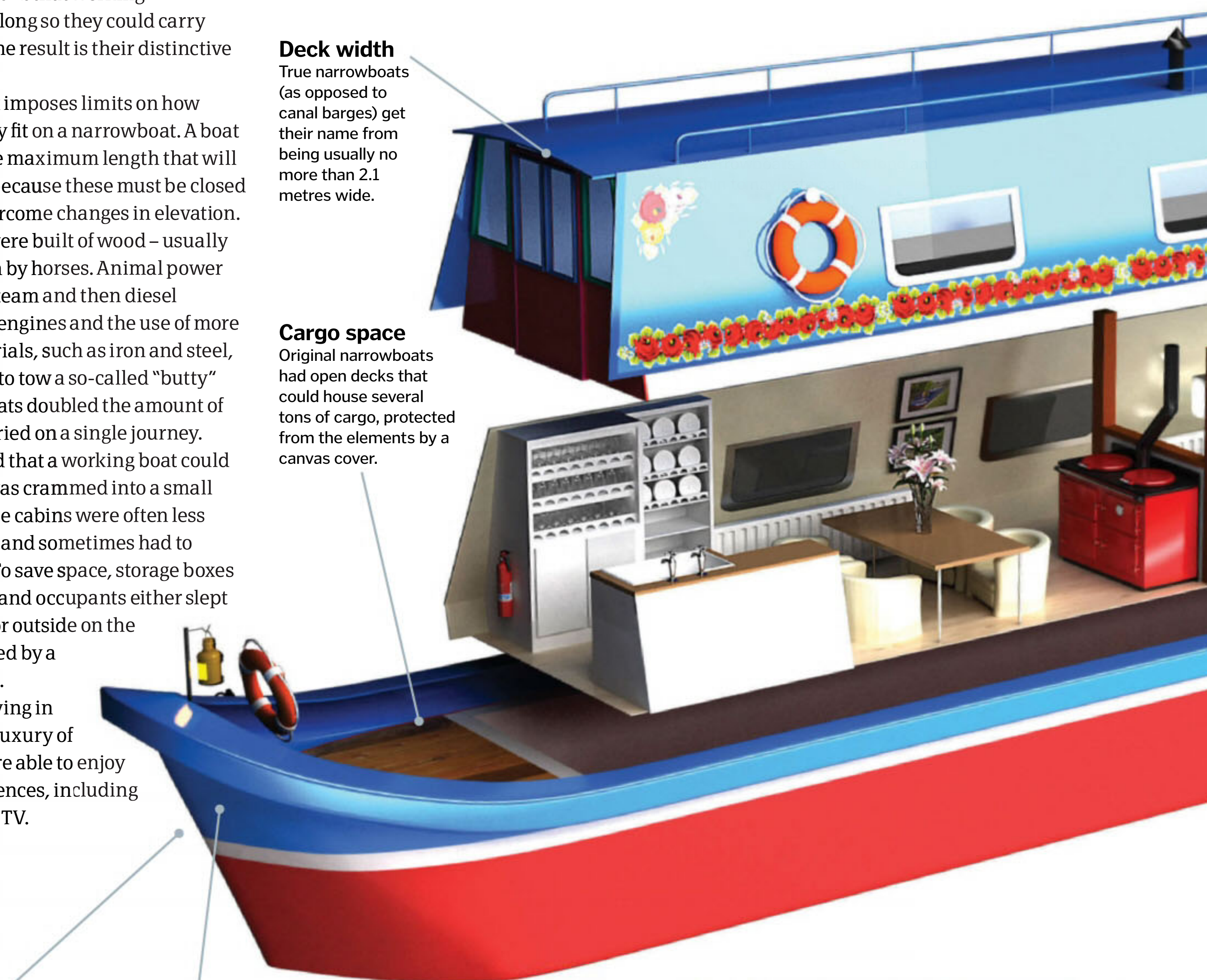
Early narrowboats were built of wood – usually oak or elm – and drawn by horses. Animal power was later replaced by steam and then diesel engines. The advent of engines and the use of more durable building materials, such as iron and steel, allowed the main boat to tow a so-called "butty" boat. These dummy boats doubled the amount of cargo that could be carried on a single journey.

To maximise the load that a working boat could carry, the crew cabin was crammed into a small space at the stern. These cabins were often less than three metres long and sometimes had to house a whole family. To save space, storage boxes could be used as seats, and occupants either slept in beds that folded up or outside on the cargo. Heat was provided by a coal-fired stove or oven.

Nowadays, people living in narrowboats have the luxury of extended cabins and are able to enjoy many modern conveniences, including electricity and satellite TV.

A modern narrowboat

These days narrowboats contain all manner of home comforts



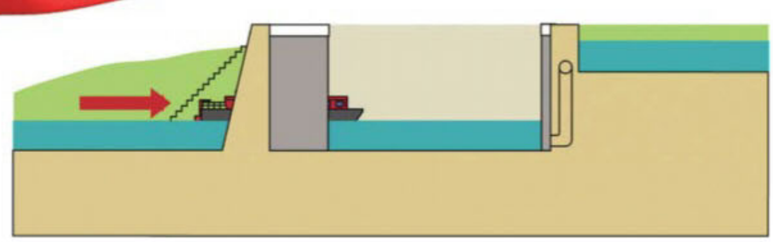
Deck width
True narrowboats (as opposed to canal barges) get their name from being usually no more than 2.1 metres wide.

Cargo space
Original narrowboats had open decks that could house several tons of cargo, protected from the elements by a canvas cover.

Bow plates
Narrowboat builders designed these to minimise resistance from the water, and sometimes to be decorative as well.

Horse power
Early narrowboats were towed from the front by horses led by a member of the crew or a child.

How canal locks work



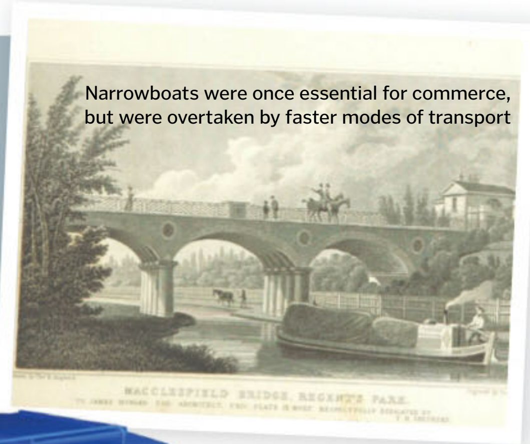
1 Entering the lock
In this example, the boat enters the lock at the lowermost gate. The water inside the lock is at the same level as in the waterway that the boat has just entered from.

Workhorses of the waterways

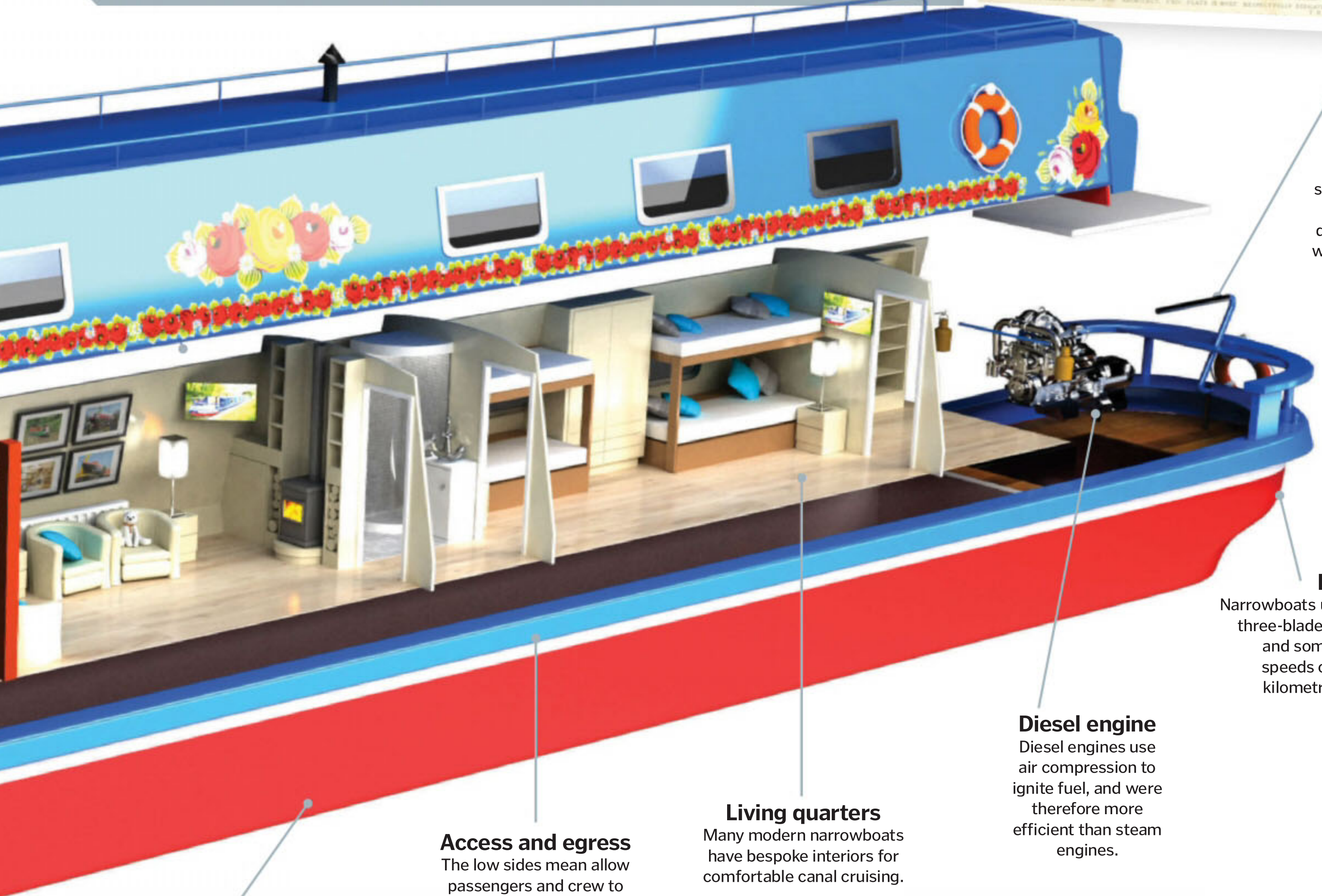
The picture of a canal boat drifting through the peaceful British countryside seems at odds with the role that narrowboats played in powering the country into the modern world. Yet, that is exactly what these boats and the waterways they travelled on were designed to do.

Britain's canals were built by industrial entrepreneurs – such as John Smeaton and Thomas Telford – from the mid-18th to the early 19th centuries. These innovators knew that an efficient transport system was needed in order to get fuel to the factories that would be the engines of the new economy. Heavy loads could be more efficiently transported by boats because the supporting effect of water reduced the effort needed to move them. However, with the arrival of fast, powerful steam trains in the 19th century, narrowboats began to lose their advantage.

In Britain, limited commercial use of canals continued into the 1940s, but further declines in their value were inevitable with the expansion of road transport.



Narrowboats were once essential for commerce, but were overtaken by faster modes of transport



Tiller
To steer a narrowboat you turn the tiller to the side opposite from the direction you want to go in.

Propeller
Narrowboats usually have three-bladed propellers and some can reach speeds of nearly 6.5 kilometres per hour.

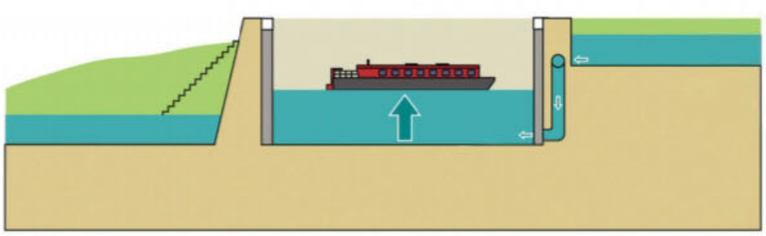
Diesel engine
Diesel engines use air compression to ignite fuel, and were therefore more efficient than steam engines.

Living quarters
Many modern narrowboats have bespoke interiors for comfortable canal cruising.

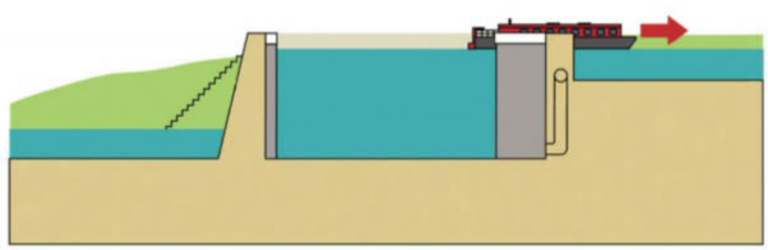
Access and egress
The low sides mean allow passengers and crew to easily get onto the towpath running alongside the canal.

Deck length
The boat's length was dictated by the shortest lock on the route, which was generally less than 22 metres.

"Narrowboat cabins were often less than three metres long"



2 Raising the boat
When the boat is fully inside the lock, the lowermost gate is closed. The lock then begins to fill up with water from the upper level, elevating the boat.



3 Leaving the lock
When the water level inside the lock is the same as that at the upper level, the uppermost gate is opened and the boat moves into the elevated waterway.

Golf buggies

How golfers and their caddies get through a round in ease and comfort

Golf may be the only sport where competitors can grab a free lift. A popular part of the sport since the 1950s, modern buggies save fuel and cut down on emissions while also being quiet so as not to disturb other golfers. The engine kicks into gear when the driver puts their foot on the pedal, not when the key is turned in the ignition. The engine then shuts off when the driver's foot is taken off the pedal. Autonomous golf buggies are being designed for use in the future to make breezing around a course even easier.

Inside a battery-powered golf buggy

Electrical drive systems have made modern buggies more eco-friendly than ever before

The Hyperloop

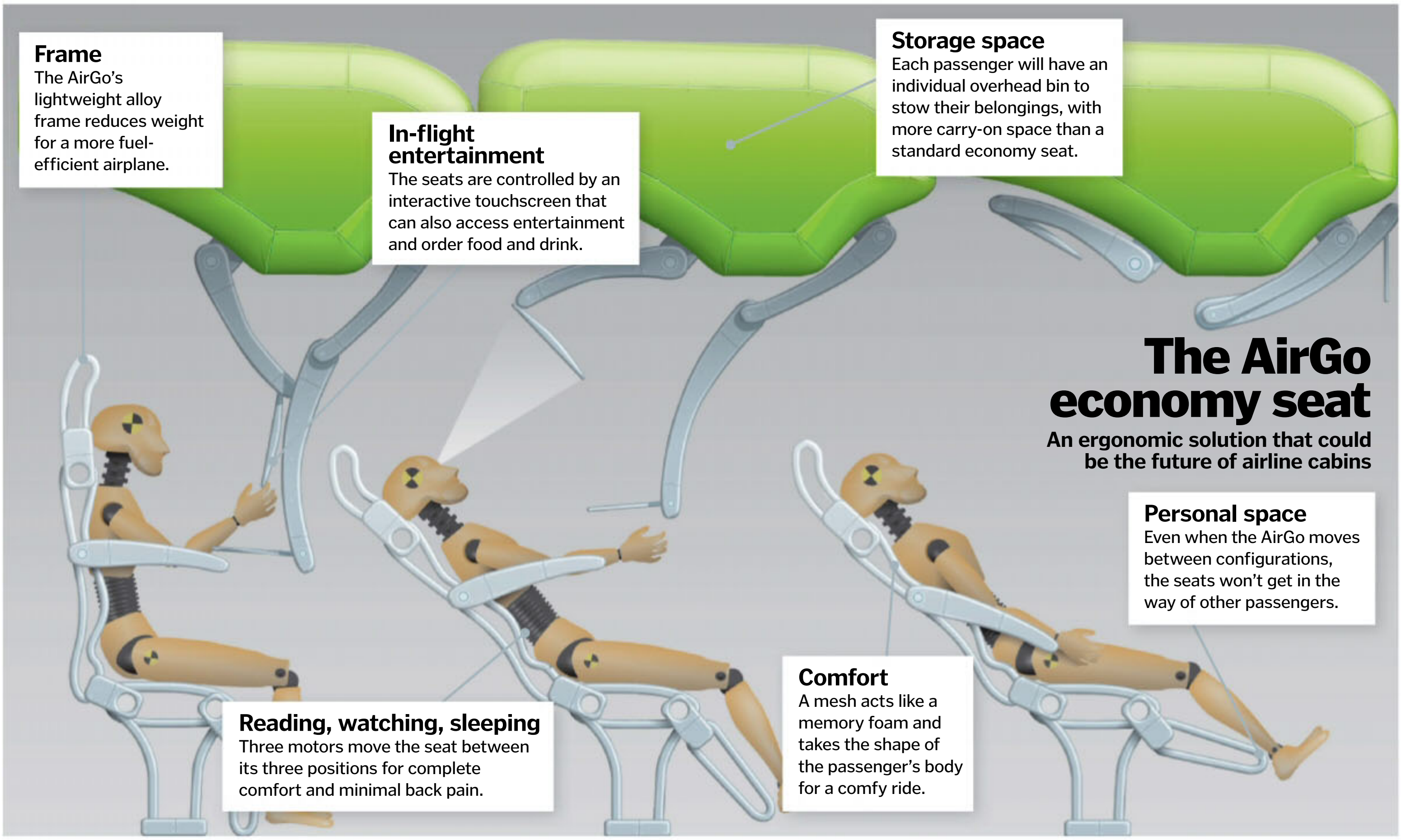
Travel at almost the speed of sound for the price of a bus ticket

The Hyperloop is a futuristic mode of transport that will almost reach Mach 1 speeds. Transportation pods will travel through a sealed tube powered by electromagnets, and the atmosphere inside the tube will be extremely thin, to a near vacuum. This will reduce the pressure and friction on the pods, allowing them to travel faster.

Only five per cent of the track will be used for propulsion and the pod will simply glide for the remainder. At 1,100 kilometres per hour, a journey from Dubai to Abu Dhabi would take just 12 minutes, around three times faster than travelling by plane. Two companies, Hyperloop One and Hyperloop Transportation Technologies, have emerged as the frontrunners for the first prototype, and are developing systems to be in place in the US, India and the UAE.

Estimated for completion in 2030, the Hyperloop is planned to be an inexpensive mode of transport that will have minimal negative impact on the environment.

Hyperloop vacuum tubes could be raised on pylons, allowing them to be built over existing roads and minimising their footprint in other areas



Next-gen airplane cabins

How airplane seats are being upgraded to be comfier, more spacious and energy efficient

With long-haul flights often a necessity for business and leisure, passenger comfort is becoming more important than ever. The AirGo economy seat is an award-winning concept that has been created to help revolutionise the experience of air travel.

The recyclable AirGo will provide passengers with more personal space, meaning their movements will not affect others, sorting the common issue of reclining seat etiquette. The new seat will have three configurations, for reading, watching TV and sleeping. Adjustable screens, footrests, neck support and back support will ensure that every passenger will find a comfortable position.

A different cabin layout has also been proposed in order to make the best use of space. In an Airbus A380, for example, the suggested four-aisle layout (single seats by the windows and three rows of double seats in between) will make the new seats up to 200 per cent more space-efficient than their current first class equivalents, with the same level of comfort at a cheaper rate. If the concept is successful, it will aim to be a mid-range option between first class and economy, and will likely be trialled for use on trains and luxury cars.

> "The recyclable AirGo will provide passengers with more pesonal space"

More upcoming airplane technology

Wi-Fi
Only a handful of commercial planes currently have wireless connectivity, but others are planning to follow suit in the future.

Mobile entertainment
Devices like AirFi will allow passengers to use their handsets to personalise their own in-flight entertainment.

Virtual reality
Onboard VR headsets could be used to help those with a fear of flying take their mind off the journey, relax and enjoy the flight.

Sleep pods
Described as a 'personal cocoon', the Air Lair will provide passengers with more room to have a sleep on long-haul flights.

Cabin customisation
For ultimate comfort the Transpose modular cabin system will allow segments of the plane to be modified for different flight lengths.

SMART CITIES

With cities growing faster than ever, what role can technology play in making them greener?

Rebuilding the urban skyline

Tomorrow's city might look familiar, but technology is making it greener, cleaner and smarter than today's

How can we make a city 'smart'? It's a question that keeps a growing number of researchers, designers and architects very busy. Usually described as a key part of the long-promised 'Internet of Things', a smart city is one in which everything is connected, both to the internet and to each other. No matter what these devices do, ultimately the motivation behind employing them in urban areas is sustainability – to use data and technology to make our cities greener and cleaner.

Take Singapore's water network. Sensors embedded throughout the system monitor water pressure multiple times a second. Any changes are reported automatically to a central server, and where a leak is suspected, a team of engineers is dispatched to repair it. Other sensors monitor the water's quality – temperature, pH and electrical conductivity can all point to contamination. In an island city with limited sources of fresh water, a system like this is absolutely invaluable.

In London, traffic lights identify areas of congestion, automatically responding to minimise delays for both road users and pedestrians. Looking further ahead, traffic lights and vehicles will be able to communicate with each other, to gather data on road usage, and to give real-time updates to drivers. On mass transport too, smart technologies are making a difference. Open data is being used to map public cycle schemes and to better understand demands on metro systems.

Leading lights

Not all of these technologies are decades away, as these cities prove

Singapore, Southeast Asia
Singapore's water supply is truly smart. Hundreds of sensors embedded within its pipes constantly measure pressure and identify leaks.

Newark, US
This indoor farm is growing different varieties of leafy greens and herbs. Wavelengths of light boost crop yield while using 95 per cent less water than traditional agriculture.

Berlin, Germany
Berlin is trialling a flexible film that can harvest solar energy. This material can be installed on a building façade, or attached to the outer surface of an air dome.

Worldwide
Many cities and towns now have smart bins that compress waste and alert collectors when they are full. Powered by a solar panel, they can also act as Wi-Fi hot spots.

"Solar-powered, internet-enabled bins schedule their own waste collections"

In Philadelphia, US, electricity generated by braking trains is automatically fed back into the city's power grid, while in the Netherlands, waste electricity is being used to charge the city's electric buses.

But retrofitting smart technologies onto existing infrastructure can be challenging. Imagine that, instead, we simply started from scratch, and designed and built a city with sustainability as its top priority. A city powered by low-carbon sources, which used smart, connected devices to keep everything moving, and which offered an improved quality of life for its residents. This was the ambitious goal of Masdar City, a purpose-built metropolis on the edge of Abu Dhabi.

When its initial design was unveiled in 2008, its developers received plaudits from all over the world. The plans included a car-free transport system that relied on driverless pods run on magnetic tracks, energy harvesting technologies in every home, and a 'net zero' approach to carbon and waste.

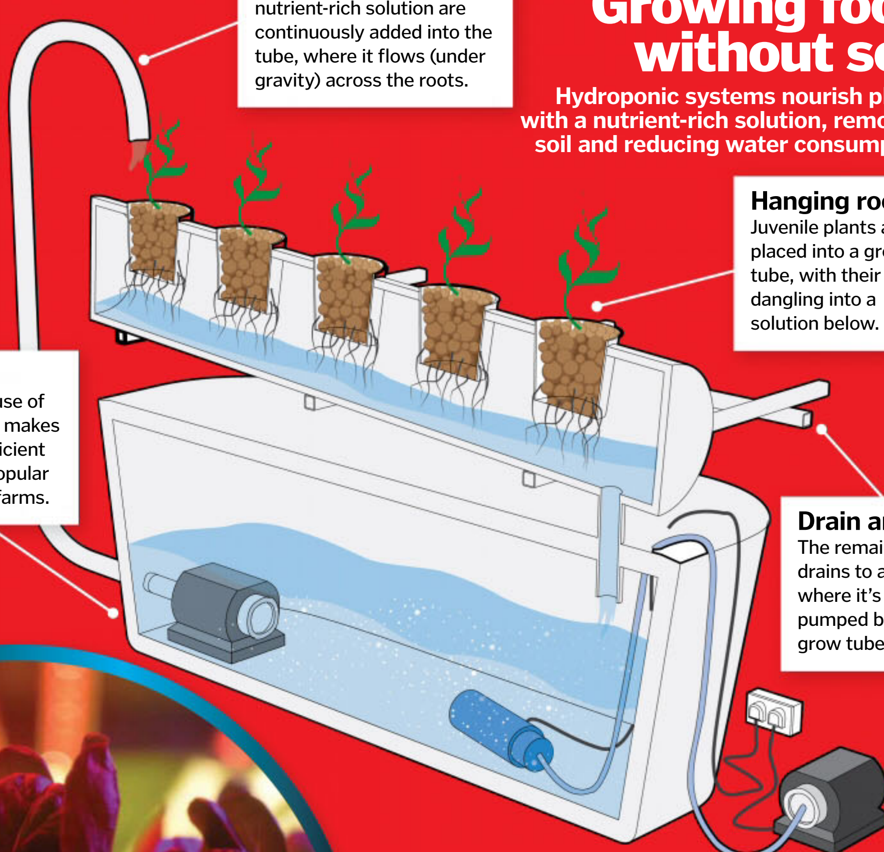
> "Plans included a transport system relying on driverless pods"

Real-life beanstalk
In this futuristic version, vertical farms growing food crops surround a skyscraper.

Vertical farms use fewer resources and less space

Growing food without soil

Hydroponic systems nourish plants with a nutrient-rich solution, removing soil and reducing water consumption



Nutrient-dense
Small drops of this nutrient-rich solution are continuously added into the tube, where it flows (under gravity) across the roots.

Hanging roots
Juvenile plants are placed into a grow tube, with their roots dangling into a solution below.

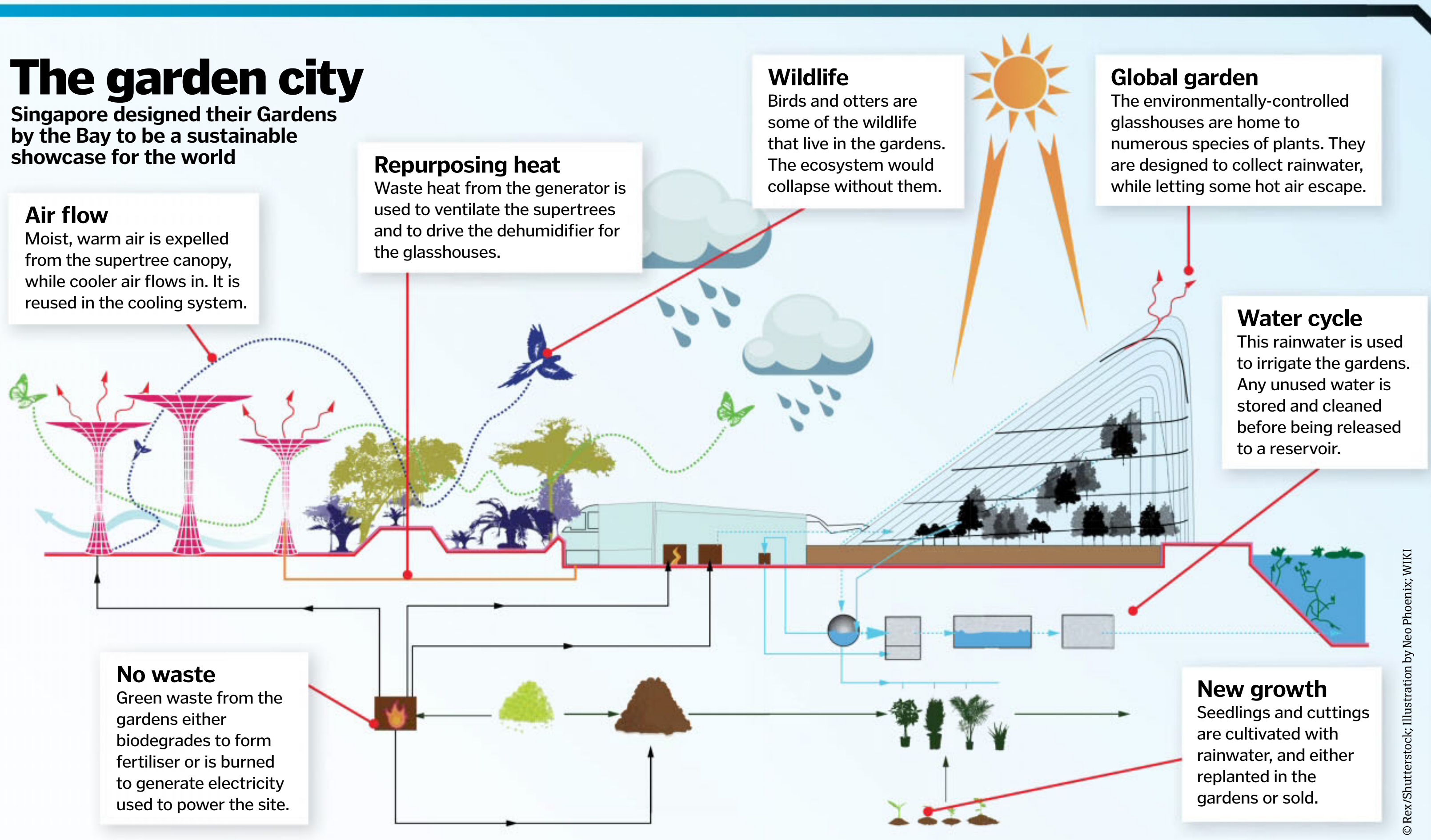
Closed cycle
The continuous reuse of nutrient-rich water makes hydroponics an efficient method, so it's a popular system in vertical farms.

Drain and pump
The remaining solution drains to a reservoir, where it's aerated then pumped back up to the grow tube.

Indoor farms use specially configured lighting to help plants grow without sunshine

The garden city

Singapore designed their Gardens by the Bay to be a sustainable showcase for the world



Singapore's sustainable city garden

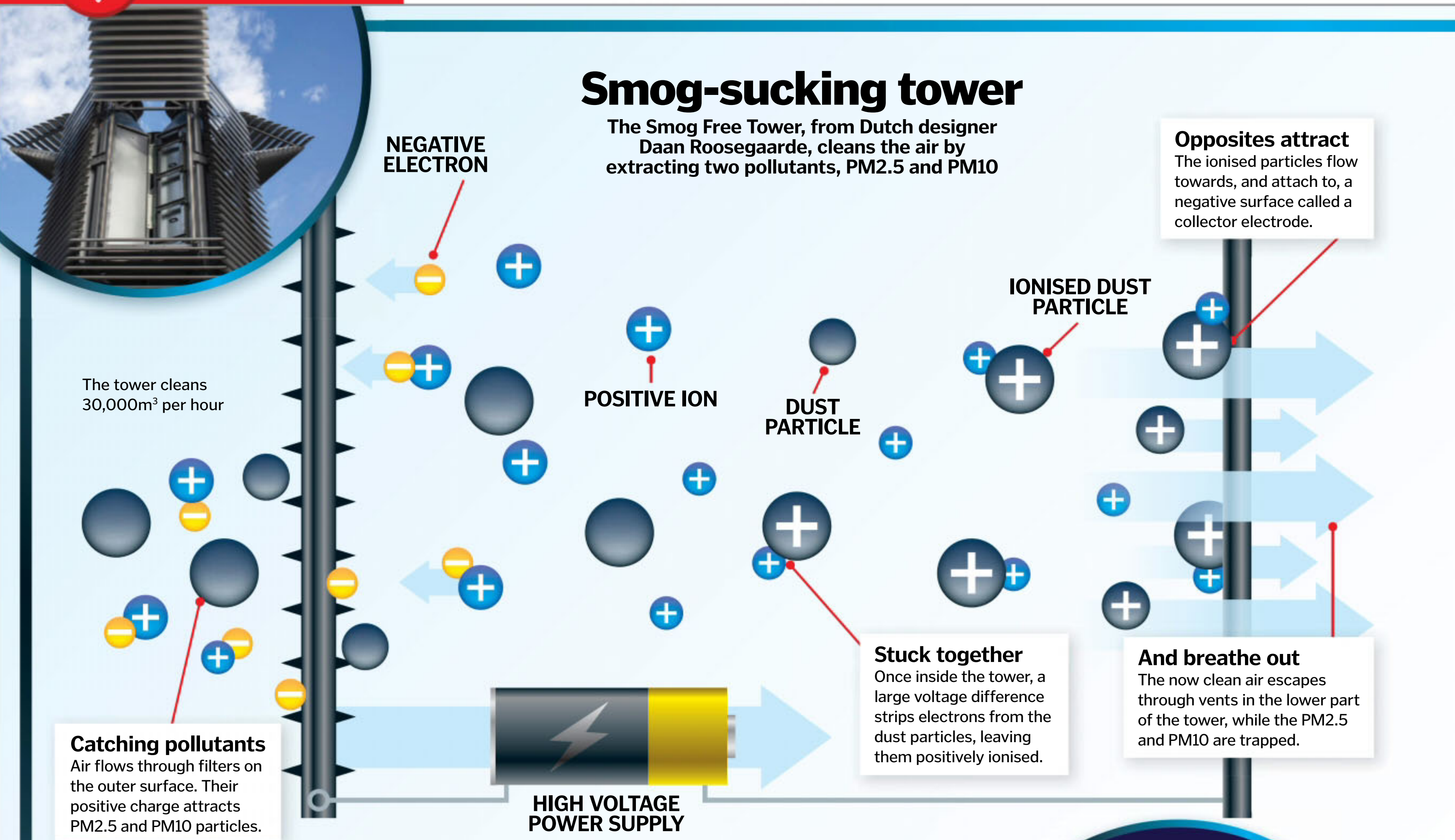
When it opened in 2011, the Gardens by the Bay in downtown Singapore were a flagship project; a way for the city to demonstrate its commitment to growing their 'Garden City' in a sustainable way. By the end of 2015, 20 million people had visited the 101 hectares of parkland, which includes two of the largest glasshouses on Earth.

The site's approach to recycling has become world famous: it collects rainwater, harvests sunlight, and uses decaying plant matter both as a fertiliser and as a source of electricity. The glasshouses are humidity-controlled partly using waste heat produced elsewhere, and the 18 iconic 'supertrees' house almost 163,000 plants, sourced from dry, semi-arid and tropical regions all over the world. Although the Gardens are self-contained, it is hoped that its approach to conservation and sustainability will inspire future cities to incorporate cleaner, greener ideas into their designs.

The Garden's supertrees are vertical gardens, fitted with solar panels and rainwater collection facilities

Smog-sucking tower

The Smog Free Tower, from Dutch designer Daan Roosegaarde, cleans the air by extracting two pollutants, PM2.5 and PM10



Buildings within Masdar City are considerably less energy-hungry than comparable structures in nearby Abu Dhabi, mainly thanks to their airtight insulation and clever design. The bulk of Masdar's hot water is provided by low-cost solar heaters, and most structures tap into the Sun's energy for their electricity needs too. But there were some deviations from the original plan.

First of all, the driverless pods now only shuttle between two stops, having largely been superseded by the growth of electric cars. The population is also much smaller than predicted; originally planned to house 50,000 residents, only around 1,000 people live in Masdar.

The economic crisis of 2008 had a significant impact on the construction schedule, meaning that to date, less than five per cent of the planned city has actually been built. And while Masdar produces much more clean energy than it uses, its developers have quietly set aside their aim of becoming the world's first zero carbon, zero waste city.

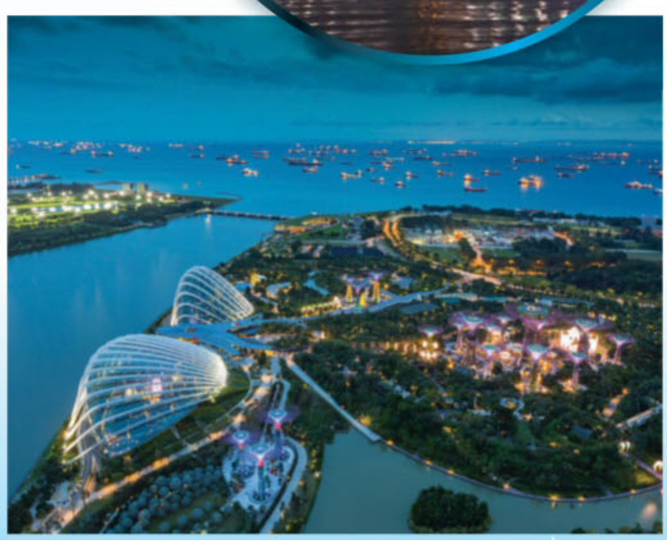
Another purpose-built sustainable city is Songdo, South Korea. With a current population of just over 100,000 – just half of what was predicted – it faces challenges on a much larger scale. Thankfully, when it comes to the use of smart technology, Songdo is leading the way.

One flagship project is its pneumatic waste disposal system. Householders separate their waste as usual, but rather than relying on fuel-belching removal trucks, the waste is all managed underground. Sensors in each bin detect how much waste it contains, and once full, it's automatically sucked through a maze of vacuum pipes to a central processing facility. There, food waste gets transformed into compost for the city's parks, and recyclable waste is cleaned and processed.

Greywater – water people have washed in – is recycled in Songdo too, and residents can track their energy and water consumption via a panel at home. Cycle paths are plentiful, and sensors across the city keep residents informed on everything from transport delays to air quality.

Despite the demonstrable benefits that technology like this has brought to these new urban regions, it's fair to say that the jury's still out on how best to build a smart city. Projects like Songdo and Masdar are a head-start on developing the necessary infrastructure, but applying it to established cities is not easy. Even so, with the way that technology is rapidly growing, it seems inevitable that our cities will have the smarts to succeed.


The nature park in the heart of Singapore is dominated by its giant glasshouses



THE RACE FOR A GREENER EARTH

From waste to water, humankind has its work cut out to achieve the eco-friendly world of tomorrow

Water desalination

"Water, water everywhere, nor any drop to drink," as the saying goes. Earth is certainly a watery planet, but as NASA images have shown us, the vast majority (96.5 per cent) of the water available to us is undrinkable seawater. With pressure on water supplies at an all-time high, cities in dry areas have resorted to removing salt from seawater to meet their needs. This process is expensive and uses huge quantities of electricity, but graphene may be able to help. This one-atom-thick material could allow water to pass through while filtering out large salt particles, with much lower energy costs than currently achievable.

This seven-metre-high air purifier has been travelling around China since October 2016

Air pollution

Studies from the World Health Organization show that the majority of large cities fail to meet minimum air quality guidelines. But numerous technologies are trying to pull pollutants directly out of the urban air. Walls, roof tiles and billboards coated in tiny particles of titanium dioxide can break down the nitrogen dioxides that impair lung function. A series of towers being trialled in China collect two types of particulate matter, called PM2.5 and PM10, which are known to contribute to smog. And in Canada, large walls of fans extract carbon dioxide from the air.

NASA's iconic 'blue marble' image highlights just how much water is on our planet

Weights, a neck brace and goggles allow researchers to experience city living with impairments

Ageing population

There will soon be more people on the planet aged 65 and over than there are children under the age of five, and an ageing population brings challenges for urban planners. Researchers have developed 'age suits' that mimic the physical challenges associated with ageing, such as sight loss or physical impairment. These are being used to help design better roads and pavements. And high-speed internet is being used to develop better links across generations in cities.

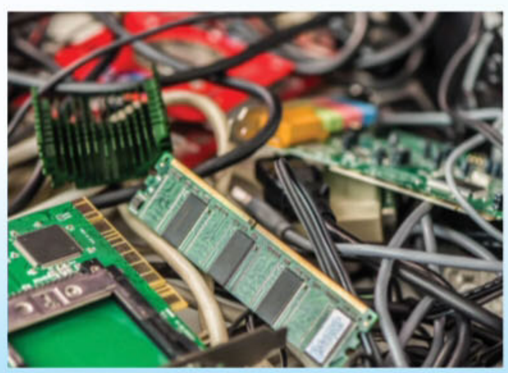
"In 2016 we dumped 40 million tons of electronic waste"

Housing demand

Around 80 per cent of Latin America's population now live in cities, and housing developers can't keep up with demands. But a Bogota-based architecture firm may have a solution. They are constructing safe, secure houses using building blocks made from waste plastic. The raw material is collected from landfill, before being cleaned and ground into a powder. Then it is melted and extruded to form beams, blocks and pillars that lock together to form buildings. A two bedroom plastic house can be built in five days, at a cost of approximately $5,000 (£4,000).

A mountain of e-waste

Electronic waste is the name given to the discarded electronic devices and domestic appliances that litter landfills across the world – in 2016 we dumped 40 million tons of it. But inside every smartphone and computer are small quantities of rare-earth metals. They are difficult to extract from the ground, so researchers are developing ways to 'mine' them from landfills. Their first success was in extracting neodymium from scrapped memory devices, and their work is ongoing.



Most e-waste is processed by hand, which exposes workers to numerous environmental hazards

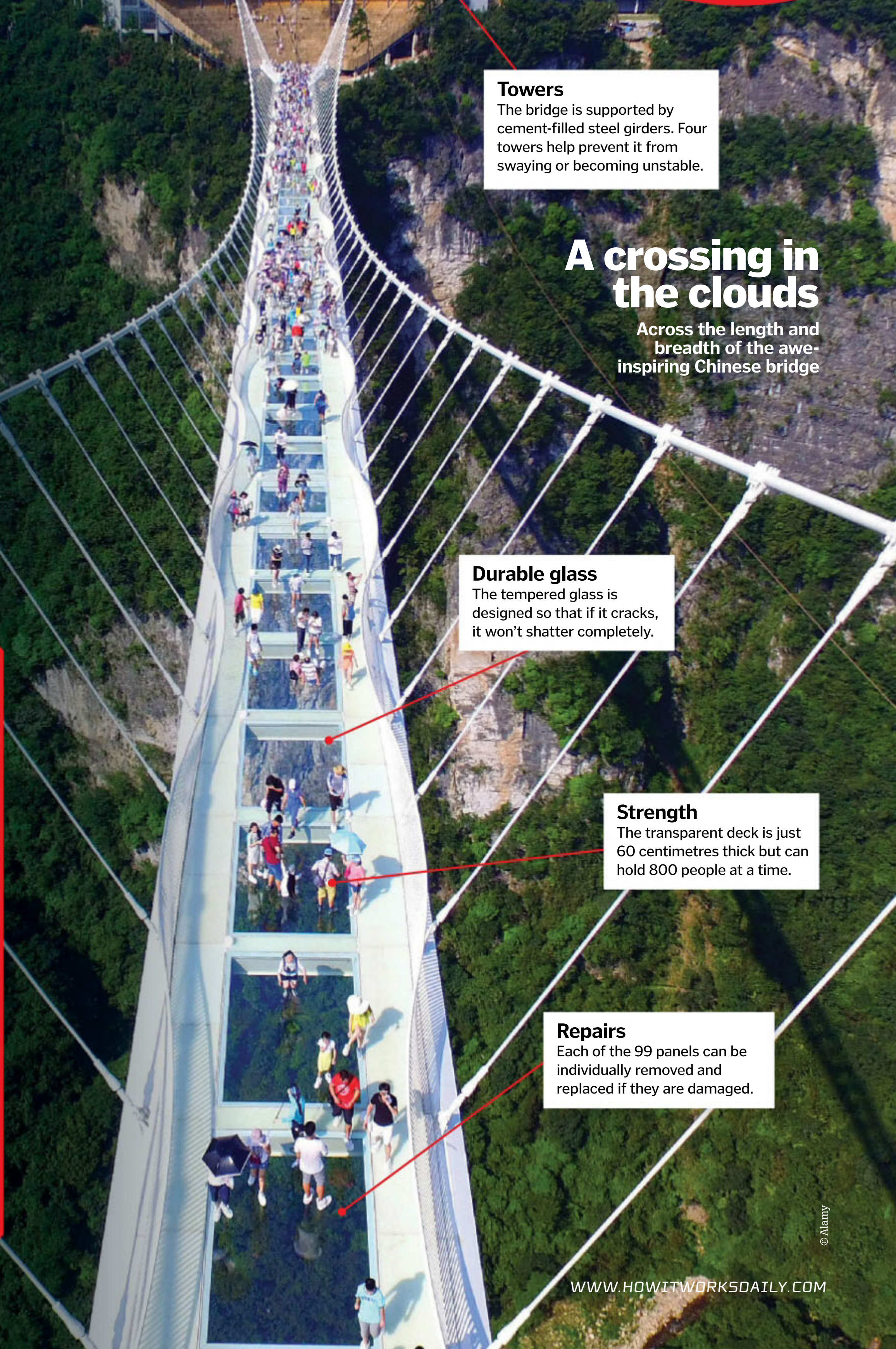
Zhangjiajie glass bridge

The engineering behind the record-breaking footbridge explained

Located deep in China's Zhangjiajie Mountains, this 430-metre crossing is an epic structure. Connecting the sides of the Zhangjiajie Grand Canyon, it's the world's highest and longest glass bridge. Hanging 300 metres in the air, traversing the bridge is not for the faint hearted, but those brave enough are treated to breathtaking views of the Zhangjiajie National Forest Park.

The bridge is constructed from 99 tempered glass panels, and to demonstrate their strength, people were invited to smash them with sledgehammers. The five-centimetre-thick panels withstood the pressure, with only the top layer of the three sheets cracking. Tempered glass is about four-times stronger than standard glass, and is produced by heat-treating. First, it heated to over 600 degrees Celsius, then 'quenched' by being blasted with high-pressure air. This cools the glass' outer layers more quickly than the centre, so the centre remains in tension while the outer surfaces are in compression, making the glass very tough.

People were invited to test the glass panels' strength



A crossing in the clouds

Across the length and breadth of the awe-inspiring Chinese bridge

Towers
The bridge is supported by cement-filled steel girders. Four towers help prevent it from swaying or becoming unstable.

Durable glass
The tempered glass is designed so that if it cracks, it won't shatter completely.

Strength
The transparent deck is just 60 centimetres thick but can hold 800 people at a time.

Repairs
Each of the 99 panels can be individually removed and replaced if they are damaged.

© Alamy

Building the bridge

The bridge was made with both style and strength in mind. The 99 glass panels are triple-layered and positioned within a steel frame, making the structure sturdy enough for 8,000 people a day to cross. The bridge was originally intended to have glass handrails, but research found that wind speed would hit the rails at 56 metres a second, creating unwanted movement. To minimise vibration, 50 glass balls weighing 500 kilograms each have been placed on the bridge, and two water tanks underneath.

The bridge took 18 months to build and opened in August 2016

Chernobyl's New Safe Confinement structure

Discover the engineering marvel that will protect the world from history's biggest nuclear accident

Images of the gutted remains of the Chernobyl nuclear power plant's Unit 4 reactor, which exploded in Soviet-controlled Ukraine during a systems test, are as chilling now as they were in 1986. History has revealed how deadly the radiation it leaked was before it was hurriedly covered with a concrete sarcophagus. Conservative estimates put the death toll at 16,000 in Europe by 2065 due to the high doses of radiation inflicted on the population.

Although the original shelter limited the fallout, it was never a long-term solution – the Chernobyl site won't be completely safe again for thousands of years. Recognising this, governments from around the world agreed in 1997 to design a new shelter to keep the planet safe from Chernobyl for at least another century. The result is the New Safe Confinement (NSC), a huge arch-shaped building designed to cover the reactor and the sarcophagus.

Built on a site about 250 metres from Unit 4, the NSC is 108 metres tall, 257 metres wide and 162 metres long. The arch is formed by 16 steel trusses that together weigh around 30,000 tons. Attached to these are 100-metre girders that support two remote-controlled cranes, which will dismantle pieces of the now crumbling sarcophagus.

To contain this lethal soup, the NSC is coated in layers of cladding capable of withstanding temperatures from -43 to +45 degrees Celsius and a Category-3 tornado. The layers are separated by depressurised spaces to keep radioactive particles in and stabilise the internal climate.

When the NSC is completed in late 2017 it will have cost at least £1.3 billion ($1.6 billion), a price worth paying to protect both us and the planet.


The NSC is longer than two Boeing 747s and tall enough to enclose the Notre Dame cathedral

Health hazards

Radiation levels in the immediate vicinity of the Chernobyl plant's damaged Unit 4 reactor are still too high for prolonged exposure. The NSC was therefore built at an accessible but relatively safe distance away. As a further precaution, the engineers are divided into teams that work in short rotations. State-of-the art safety and monitoring measures have also been put in place. These include the construction of radiation-proof changing rooms, medical screening centres and decontamination facilities. Direct exposure to radioactivity isn't the only danger workers face though. The original sarcophagus had to be stabilised because parts of it were in danger of collapsing. Its structural integrity is now constantly monitored along with seismic activity and levels of radioactivity in the area.


Radiation dose limits for NSC construction workers are below exposure levels from a dental X-ray

CHERNOBYL TIMELINE

The battle to contain a nuclear disaster

Chernobyl reactor explodes
April 1986

During a systems test, an explosion in Unit 4 destroys the reactor hall and exposes the environment to harmful radiation.

Evacuation of the area
1986

Residencies within a 30-kilometre exclusion zone are deemed heavily contaminated and are evacuated.

Original sarcophagus built
Late 1986

To control the release of radioactive substances a concrete sarcophagus is built over Unit 4.

Shelter Implementation Plan
1997

An international coalition agrees to fund a long-term replacement for the reactor's original sarcophagus.

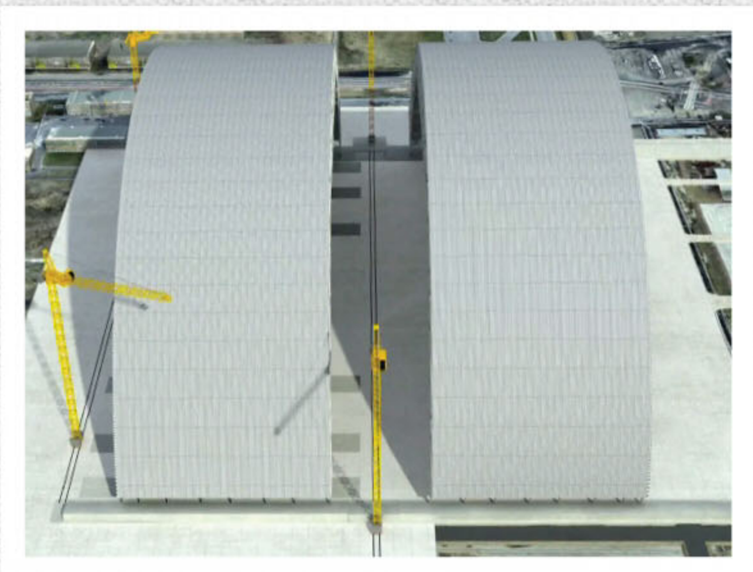
"The NSC can withstand temperatures from -43 to +45 degrees Celsius"

Transporting the arch

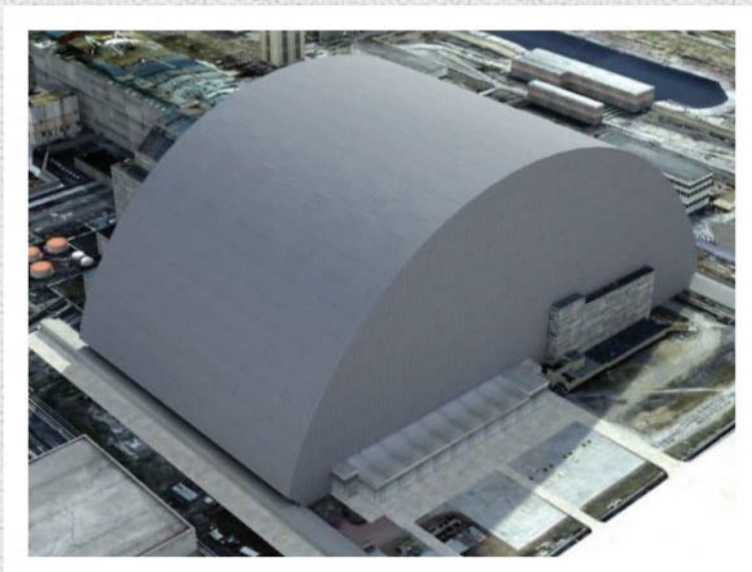
The amazing mechanics used to move the NSC into position over the sarcophagus

1. Construction site
The NSC was built on a specially designed construction platform near the reactor. An area was cleared and covered in thick concrete to minimise radiation leakage from underground. The platform was then built on this concrete base.

2. Two stages
Because of its massive size, the NSC arch was built in two halves. Construction on the first half was largely completed before it was moved off the main construction platform so work could begin on the second half.



3. Perfect seal
Once both arches were completed they were pushed together. The joint was sealed on the inside and outside layers to make sure no radiation leaked into the atmosphere once the arch was in place over the old sarcophagus.



4. On the rails
The construction platform was connected by purpose-built rails to the site of the reactor. It took three weeks to move the finished arch along these rails until it covered the site of the explosion.

Site preparation
2008
Stabilisation of the original sarcophagus ensures it won't collapse before construction begins on the NSC.

NSC construction begins
2012
Building work commences on the first half of the NSC arch. The second half soon follows, and the two are then connected.

The arch is moved
November 2016
Following its completion in 2015, the arch is moved over the site of the devastated Unit 4 reactor.

NSC completion
2017
Completion of the NSC and commencement of decontamination operations are planned for later this year.

DAY IN THE LIFE OF

A wind turbine technician

Take a trip out to sea with the teams who keep offshore wind farms up and running

The Teesside Wind Farm is the northeast of England's first large-scale offshore wind farm. 27 turbines generate low-carbon renewable electricity, powering 40,000 homes and offsetting 80,000 tons of carbon dioxide.

Each high-tech turbine is serviced by a team of specialist technicians who perform essential maintenance. Jonny Corrigan is a senior technician and site leader who manages the upkeep of the Siemens-built wind turbines. The job has its fair share of hazards, and it's up to Jonny and his team to keep the farm operational in the harsh conditions of the North Sea.

TOOLBOX TALK
7am

The working day begins onshore with a site brief. I deliver a talk to make sure everyone knows what's in store for the day ahead. We hear about faults via a SCADA (Supervisory Control And Data Acquisition) system that sends us a code of what sort of issue it is. We analyse the problem fully before setting off so we know what tools and equipment we need.

FINAL CHECKS
7:30am

The teams are organised and we get ready to go offshore. Before we venture out to sea, we need to check the weather forecast, as heavy winds and lightning can affect an operation. It is also likely that we will need lifting equipment, as many of the components that we repair and replace are incredibly heavy. The larger equipment is lifted using cranes.

OUT TO SEA
8am

Once our marine controller gets the go-ahead from the River Tees estuary coastguard, we're ready to go. We

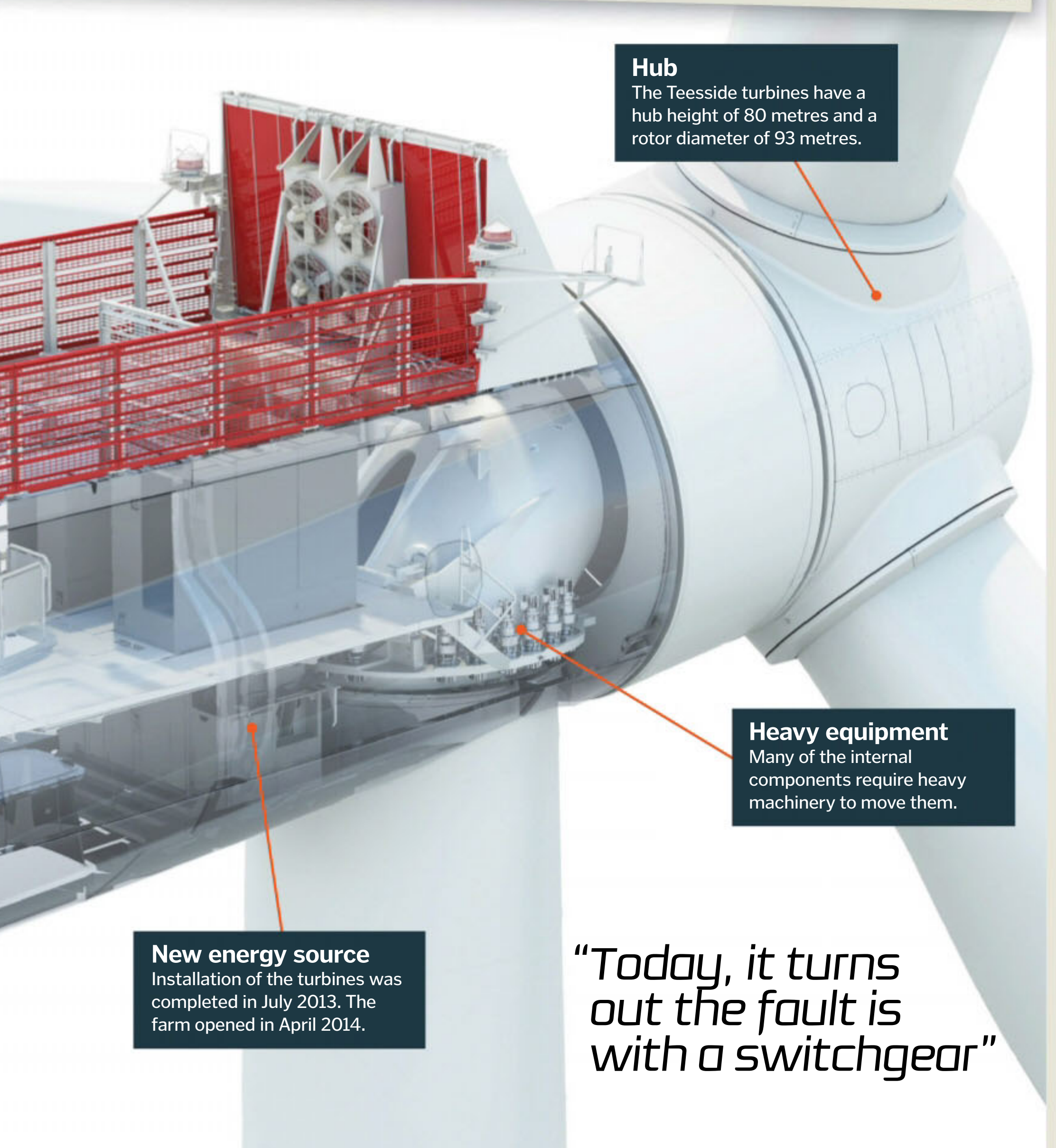
Heavy machinery is often required to complete a job

Jonny Corrigan is the site leader for Siemens

The technicians have a good grasp of electrics, mechanics and hydraulics

Each turbine can produce an average of 2.3 megawatts of power of wind energy

In 2015, 11 per cent of Britain's electricity was generated from wind power



"Today, it turns out the fault is with a switchgear"

access the wind farm in a Windcat workboat, which is a type of CTV (Crew Transfer Vessel). It's important not to forget any equipment or tools that we may need, as it's a half-hour journey to the farm.

ON THE FARM
8.30am

On arrival we transport all our equipment out of the boat and onto the turbine. We then contact the client to make sure that it's safe to access, and also whether the turbine already has any outstanding work or upgrades. Using specialist software, we plug our laptops into the computer systems and investigate further what sort of fault it is.

ANALYSING THE FAULT
10am

Today, it turns out the fault is with a switchgear. Every turbine has one and it isn't normally meant to be replaced. It's a huge piece of electrical equipment that weighs 700 kilograms. As it's such a rare fault there's no set procedure, so we have to take time to plan how to approach the work.

UP TO THE TOP
11am

The majority of the wind turbine is basically empty. We can access the top using ladders or a man-riding lift. The main equipment, including the generator, is here. A team can be made up of as little as two people, but we usually have three-person teams. Luckily, this fault doesn't require us to shut down the turbine.

HEAVY LIFTING
1pm

The switchgear has a cracked baseplate. Due to its weight we use a tackle rail and a moveable platform to shift it out of the turbine. It's so heavy that we need to use specialist lifting accessories to get the switchgear onto the vessel and back to shore. We'll need to commission a replacement switchgear as soon as possible.

HEADING BACK TO SHORE
5pm

On large tasks like this the work can take all day. This is a major repair and a replacement won't arrive for three days. We return to dry land at the end of the day to unload the vessel. We need to make sure all the relevant paperwork is done, which will take us through to about 6.30pm.

Walkie-talkies

What are the advantages of a two-way radio over a mobile phone?

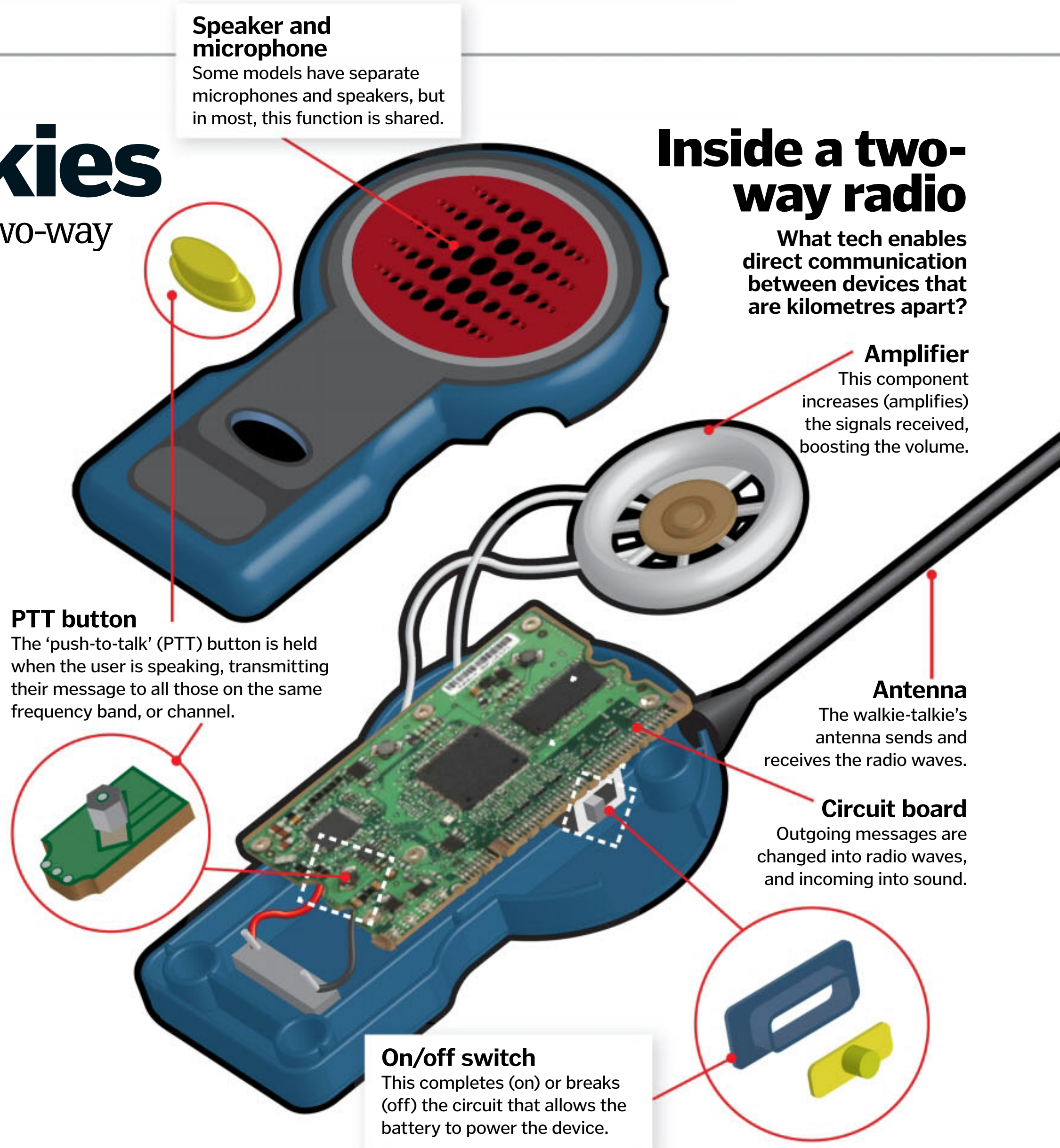
Still widely used by emergency services and militaries, among others, walkie-talkies are handheld devices that can send and receive radio waves. Unlike mobile phones, which require both caller and receiver to be in range of a cell tower, walkie-talkies communicate over a shared radio wave frequency. As long as the two devices are within range of each other – up to 60 kilometres for some models – they can communicate.

In most devices, the loudspeaker doubles up as the microphone, so users can't talk and listen at the same time. Because the communication frequency can be shared between multiple devices, only one person on that frequency can speak at once, which is useful for groups receiving orders, such as soldiers.

Walkie-talkies are useful in many industries, from construction to event organising

Inside a two-way radio

What tech enables direct communication between devices that are kilometres apart?



Bubble wrap

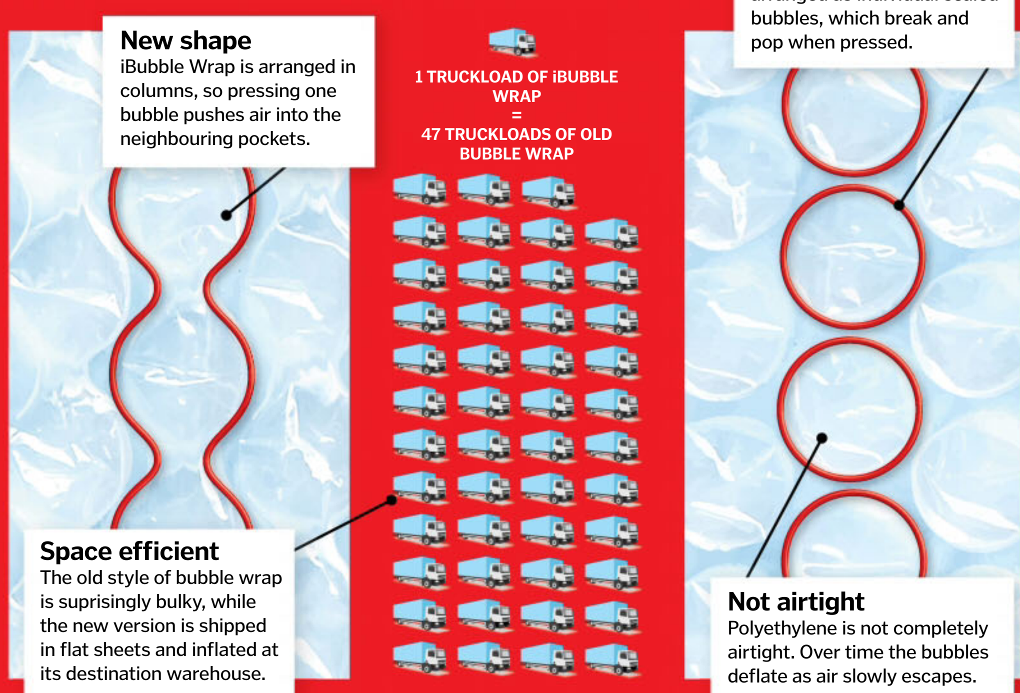
How this packaging film is made, and why some bubbles no longer pop

Bubble wrap is a flexible and lightweight packaging film used to protect objects during transit. But despite its main purpose, many of us value it more as a method of stress relief, for the strangely therapeutic act of popping the bubbles.

The packaging is made from polyethylene resin, which is melted at approximately 180 degrees Celsius and squeezed out of an extruder in two stacked sheets. One of the sheets is wrapped over a large drum covered in holes, and suction is applied to draw the plastic into the holes, forming the bubbles. The second layer of film is then joined to the first, trapping air inside the bubbles.

All bubble, no pop

Sealed Air Corp's new production method makes bubble wrap more space efficient, at the expense of the characteristic 'pop'



Wood chippers

How these powerful shredders chop tree trunks into tiny chunks

Garden waste can usually be put to good use on a compost heap, but dealing with big branches and hefty tree stumps is not so straightforward. Wood chippers are used to reduce large, heavy tree remains into more manageable chunks.

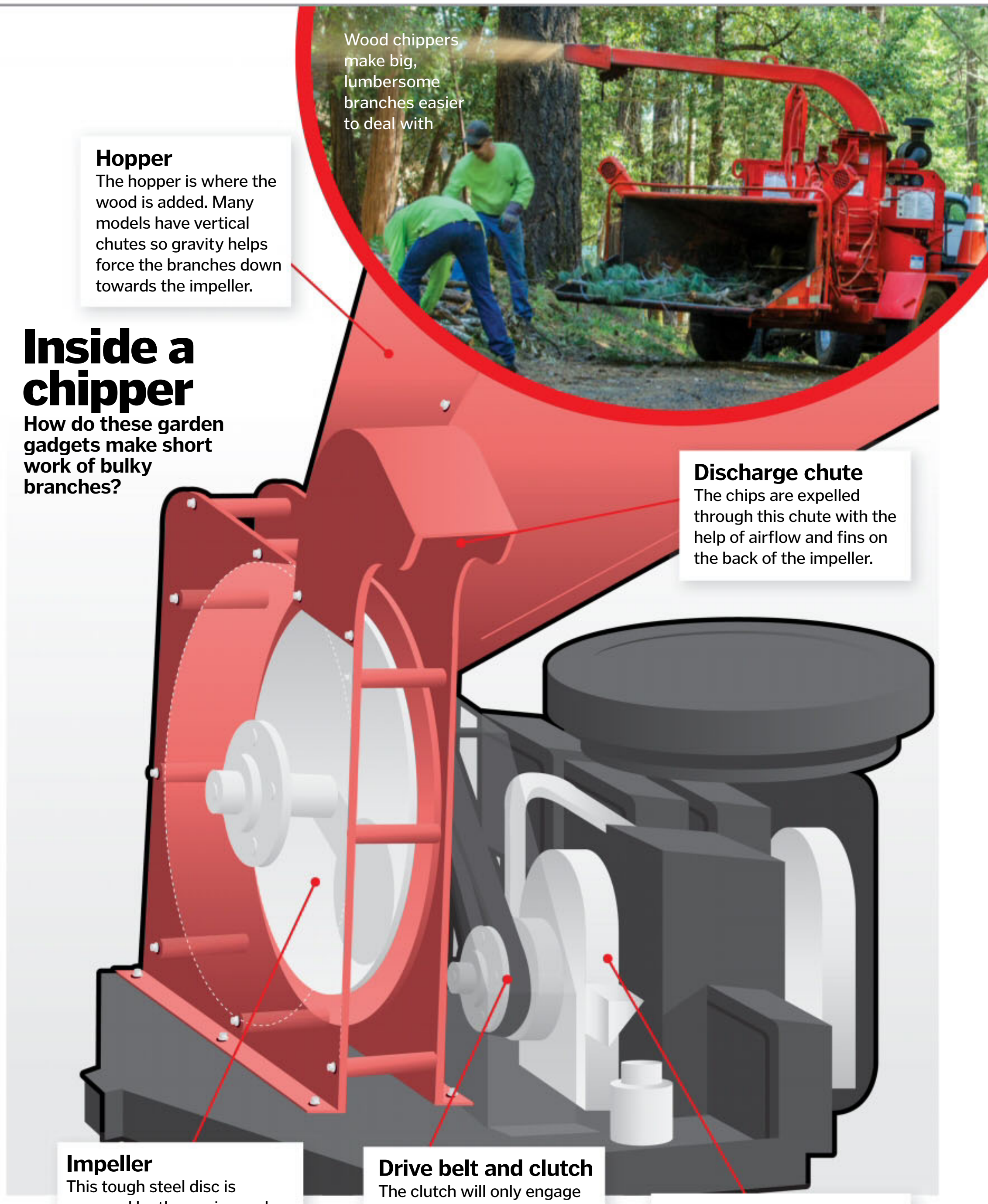
Chippers typically contain a hopper, an impeller and a discharge chute. The hopper is a wide chute that the branches or tree stumps are placed in, leading down to the impeller. The impeller is a strong disc, usually steel, which has a blade (known as a chipper knife) built in, and cuts through wood by spinning very quickly.

In some models, the chipper knife can be angled in such a way that it effectively pulls the incoming wood down the chute towards the blades, which slice it into little chips. The wood chips are then directed out through the discharge chute by metal fins on the back of the impeller, helped along by airflow through vents in the body of the chipper. The chips can then be repurposed around the garden to create paths, cover flowerbeds, or used to make mulch.

Most wood chippers are powered by gas engines, which power a crankshaft that is attached to a clutch. To make sure the blades can cut effectively, the clutch will only connect to the drive belt, which turns the impeller, when the engine reaches a certain speed. If the impeller started spinning straight away, the blades would struggle to cut through the tough wood.

Inside a chipper

How do these garden gadgets make short work of bulky branches?



Wood chippers make big, lumbersome branches easier to deal with

Hopper
The hopper is where the wood is added. Many models have vertical chutes so gravity helps force the branches down towards the impeller.

Discharge chute
The chips are expelled through this chute with the help of airflow and fins on the back of the impeller.

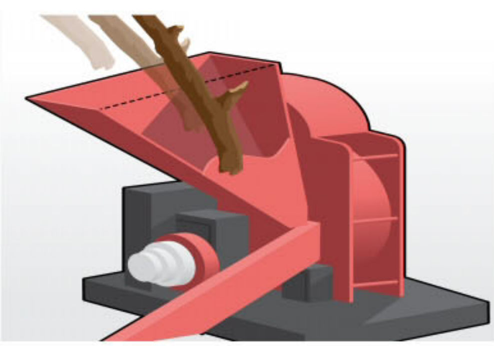
Impeller
This tough steel disc is powered by the engine and rotates at great speed. The in-built chipper knife slices the wood as the impeller spins.

Drive belt and clutch
The clutch will only engage the drive belt to make the impeller turn when the engine is running fast enough for the blades to slice wood effectively.

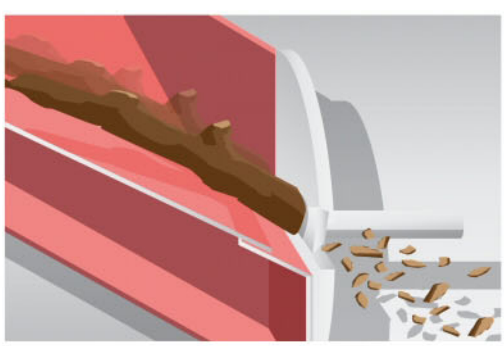
Engine
Wood chippers typically use gas engines, although some models are electric. The engine turns a crankshaft that is connected to the clutch.

Self-feeding systems

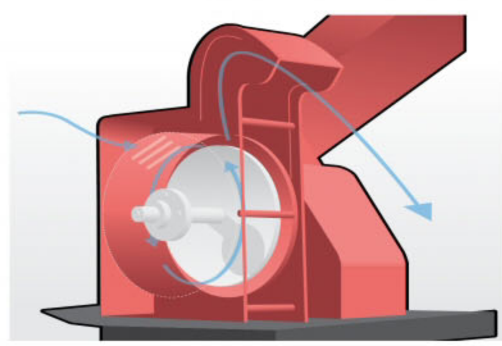
Some wood chipper models are designed to pull branches in by themselves



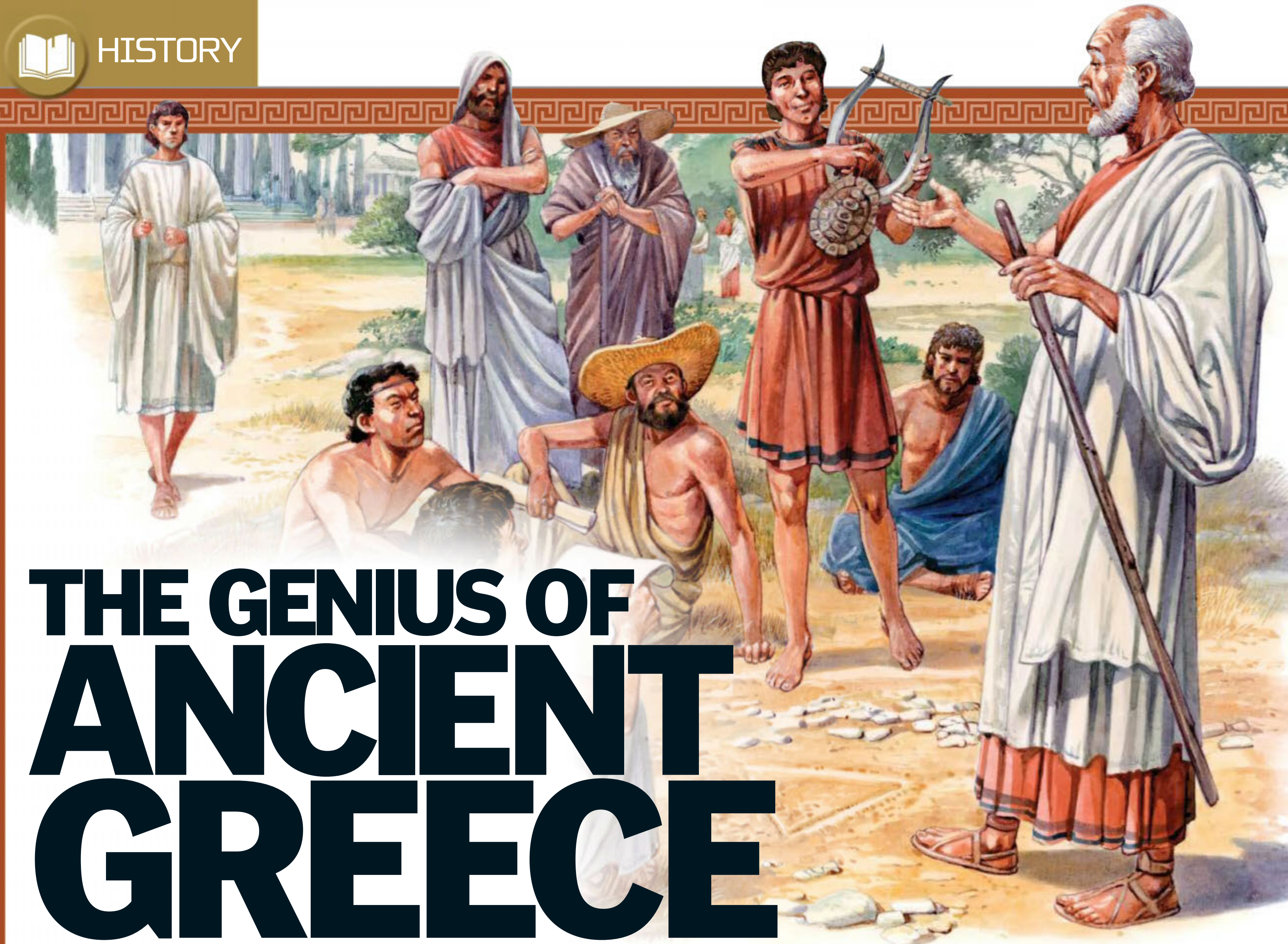
1 Easy use
The hopper is vertical, so gravity helps initially direct the branches to the chipping chamber. There's no need for any risky force-feeding from the user.



2 Angled blades
The impeller's chipper knife can be angled in such a way that it effectively grabs the incoming wood and pulls it in to the chamber.



3 Airflow
As air flows in through the vents and out of the discharge chute, it creates a relative vacuum in the chipping chamber to help suck subsequent branches in.



THE GENIUS OF ANCIENT GREECE

How the inventions, discoveries and culture of this great civilisation changed the world

Ancient Greece was pivotal for the development of Western culture and society. As Europe moved into the Iron Age, Greece was a leading light in the progression of ancient civilisation. Athens is often credited as the key player in this advancement, but other Greek states like Corinth, Thebes, and even the warlike Sparta, also contributed. Ancient Greece improved almost every facet of the economy, society, military and politics. The Greek phalanx was one of the most feared military formations in the ancient world; Greek theatres held the best plays, and athletes competed at the pinnacle of ancient sport: the Olympics.

Greek architects designed some of the finest ancient structures, and philosophers questioned the world in new ways. Homer's works *The Iliad* and *Odyssey* were unmatched in their time. Unlike civilisations before it, it's believed many educated people in ancient Greece were literate. Hundreds of words in the English language have their origins in the ancient Greek language such as 'encyclopaedia', 'telephone' and 'microscope'. The word 'democracy' is another, and it comes from the Greek 'demokratia', which means 'power to the people'.

Greek city-states were ruled by kings for the majority of the civilisation's history, but for a brief period around the 5th century BCE, Athens was a democracy. It wasn't the same system as we know it today (women and slaves weren't allowed to vote), but this incredibly important development has shaped world politics ever since, and anyone who can vote today owes it to the Greeks.

The divisions of the city-states curtailed scientific advancement as regions often fought among themselves. Finally unified under Alexander the Great in 336 BCE, Greek trade boomed and its culture spread throughout the Mediterranean, Asia Minor and North Africa. The Romans may have conquered Greece, but they were so impressed by its culture and technology, they copied Greek mythology, engineering, architecture and military tactics. The influence of ancient Greece is so important to the Western world that if it had been destroyed during their many conflicts with Persia, European civilisation could have turned out very differently.

Major events in ancient Greek culture

6,000 BCE
First human settlement
The first Neolithic activity in Greece, including evidence of early agriculture.

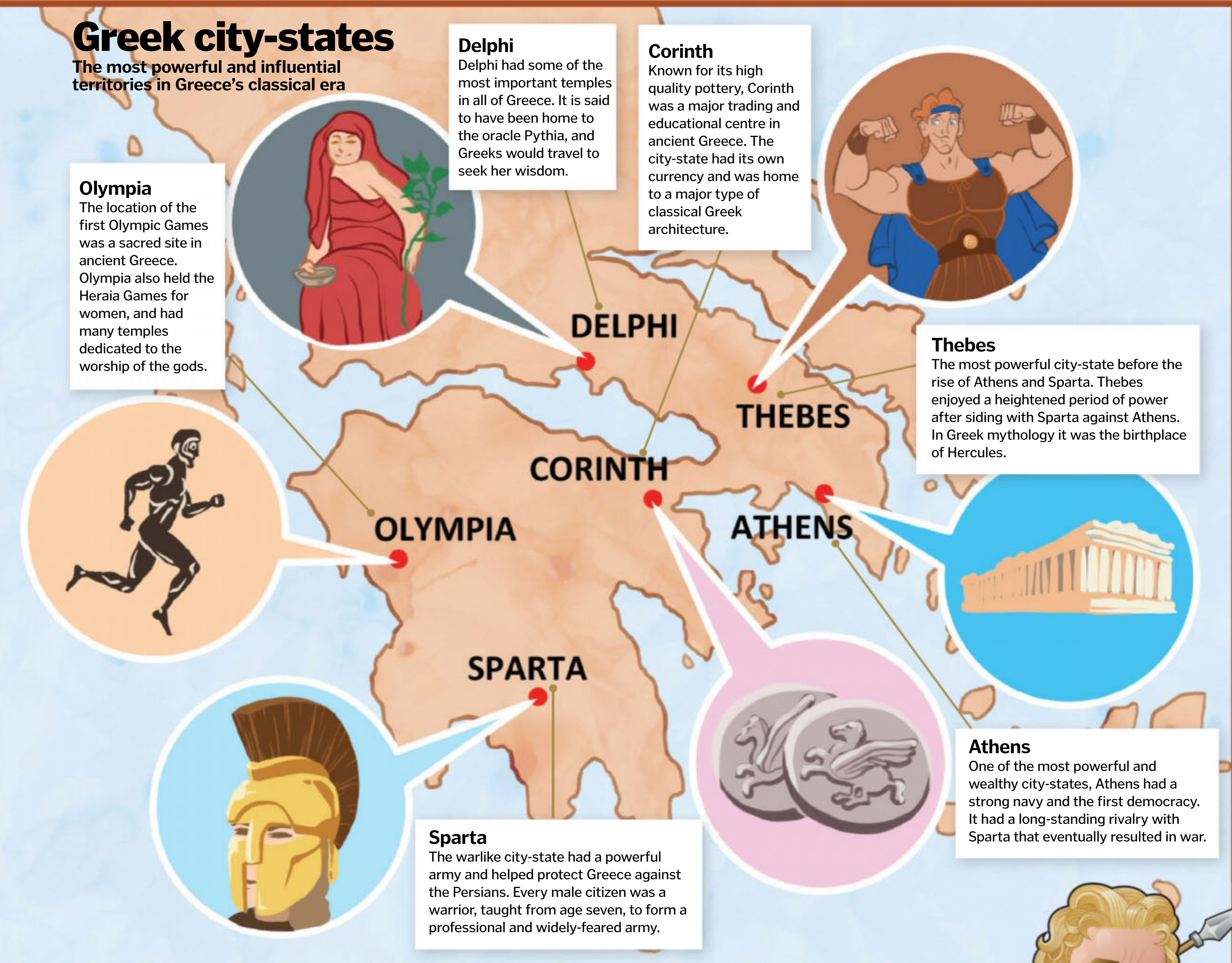
2,700 BCE
Minoan civilisation on Crete
The Minoan civilisation blooms under a system with no hierarchical structure.

1,500 BCE
Mycenaean era
Greece is now in the Bronze Age and the Mycenaean culture develops the Greek language.

c.900 BCE
First pottery
Made in a classical geometric style, the first pottery unique to Greek culture is made.

Greek city-states

The most powerful and influential territories in Greece's classical era



Olympia
The location of the first Olympic Games was a sacred site in ancient Greece. Olympia also held the Heraia Games for women, and had many temples dedicated to the worship of the gods.

Delphi
Delphi had some of the most important temples in all of Greece. It is said to have been home to the oracle Pythia, and Greeks would travel to seek her wisdom.

Corinth
Known for its high quality pottery, Corinth was a major trading and educational centre in ancient Greece. The city-state had its own currency and was home to a major type of classical Greek architecture.

Thebes
The most powerful city-state before the rise of Athens and Sparta. Thebes enjoyed a heightened period of power after siding with Sparta against Athens. In Greek mythology it was the birthplace of Hercules.

Athens
One of the most powerful and wealthy city-states, Athens had a strong navy and the first democracy. It had a long-standing rivalry with Sparta that eventually resulted in war.

Sparta
The warlike city-state had a powerful army and helped protect Greece against the Persians. Every male citizen was a warrior, taught from age seven, to form a professional and widely-feared army.

Macedonian unification of Greece

The Peloponnesian Wars (431-404 BCE) tore Greece apart, with the hegemony of Athens broken by Sparta and its allies. Greece remained divided, with a series of uneasy alliances leaving it weak and open for invasion. Around this time the power of Macedonia was growing and King Philip II of Macedon took advantage of a weakened Greece. His army defeated a strong alliance of Athenian and Theban soldiers at the decisive Battle of Chaeronea in 338 BCE. Sparta did not join in the battle but would also later be defeated. Philip was now the undisputed ruler of Greece, and although he was later assassinated, this brought his son Alexander III to the throne. A born leader, Alexander the Great unified Greece under his rule and made it his intention to bring the Persian Achaemenid Empire to its knees. Alexander went on to lead one of the most powerful empires in the ancient world, which stretched from Greece in the west to India in the east.

Philip and Alexander's rule united Greece and established it as a major military power

ARCHAIC PERIOD

c.800 BCE

Works of Homer
The 'blind bard' writes the poems *The Iliad* and *Odyssey*.

776 BCE

Olympic Games held
The first Olympics take place as a festival dedicated to Zeus. The event is held every four years for centuries.

740 BCE

Greek alphabet
Created from a Phoenician script, evidence of the first Greek alphabet is found.

700 BCE

Birth of musical study
Sparta and Argos hold the first organised studies of musical theory and the first documented musical competitions.

The Acropolis

Athens' defining citadel became an enduring symbol of ancient Greek architecture

The Acropolis rises 150 metres above Athens and is around six hectares in size

Many major Greek cities were dominated by an Acropolis at their centre. Meaning 'high city', it was a well-defended hill that citizens would retreat to when the city was under attack. The city-states of Thebes and Corinth both had an Acropolis, but by far the most famous of these citadels stood in the centre of Athens. The original structures were improved after victory at the Battle of Marathon in 490 BCE, but were destroyed by Xerxes' Persian troops when they sacked Athens ten years later.

After the Persian defeat at Salamis, the city used its wealth to restore splendour to the Acropolis. Vast building projects got underway and the area became a huge centre of worship for the goddess Athena, the patron deity of Athens.

The grandest temple of all was the Parthenon, which was constructed between 447 and 432 BCE. It housed a magnificent ivory statue of Athena and was the store of the city's gold reserves. The area became a place of worship and culture rather than just defence, with the temples of Athena Nike, Erechtheion and Propylaia also built in a 50-year period. With the help of modern restoration efforts, the Parthenon stands above the city to this day.

> "The area became a huge centre of worship for the goddess Athena"

The Acropolis of Athens

How grand building programmes in the 5th century BCE turned the Acropolis into a sprawling citadel

Athena Nike
Inside the temple was a wooden statue of Athena. She held a helmet and a pomegranate tree to symbolise war and peace.

Monumental gateway
Known as a Propylaia, this was a decorative entrance to the complex. Its columns and roofs made it an imposing structure.

Acropolis entranceway
The main entrance to the Acropolis was a wide stone staircase that led to the monumental gateway.

Erechtheion
This most sacred temple in Athens was in Greek mythology – the site where Athena and Poseidon disagreed on who would have control of the city.

Natural entrance
The Propylaia was constructed around the natural entrance to the Acropolis and citizens ascended via a ramp and marble steps.

625 BCE
Advancements in pottery
Black figure pottery becomes popular in Greece, but is later superseded by red figure pottery.

621 BCE
Draco's code of law
Devised by an Athenian aristocrat, these became the city's first written law codes and legal system.

594 BCE
First coins
Athens now uses a currency as trade and industry begin to develop.

508 BCE
Birth of democracy
'The father of Athenian Democracy', Cleisthenes introduces a new political system as the public become involved in politics.

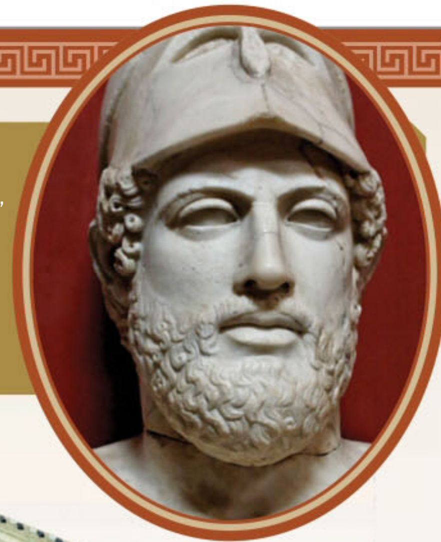
CLASSICAL PERIOD

The Parthenon

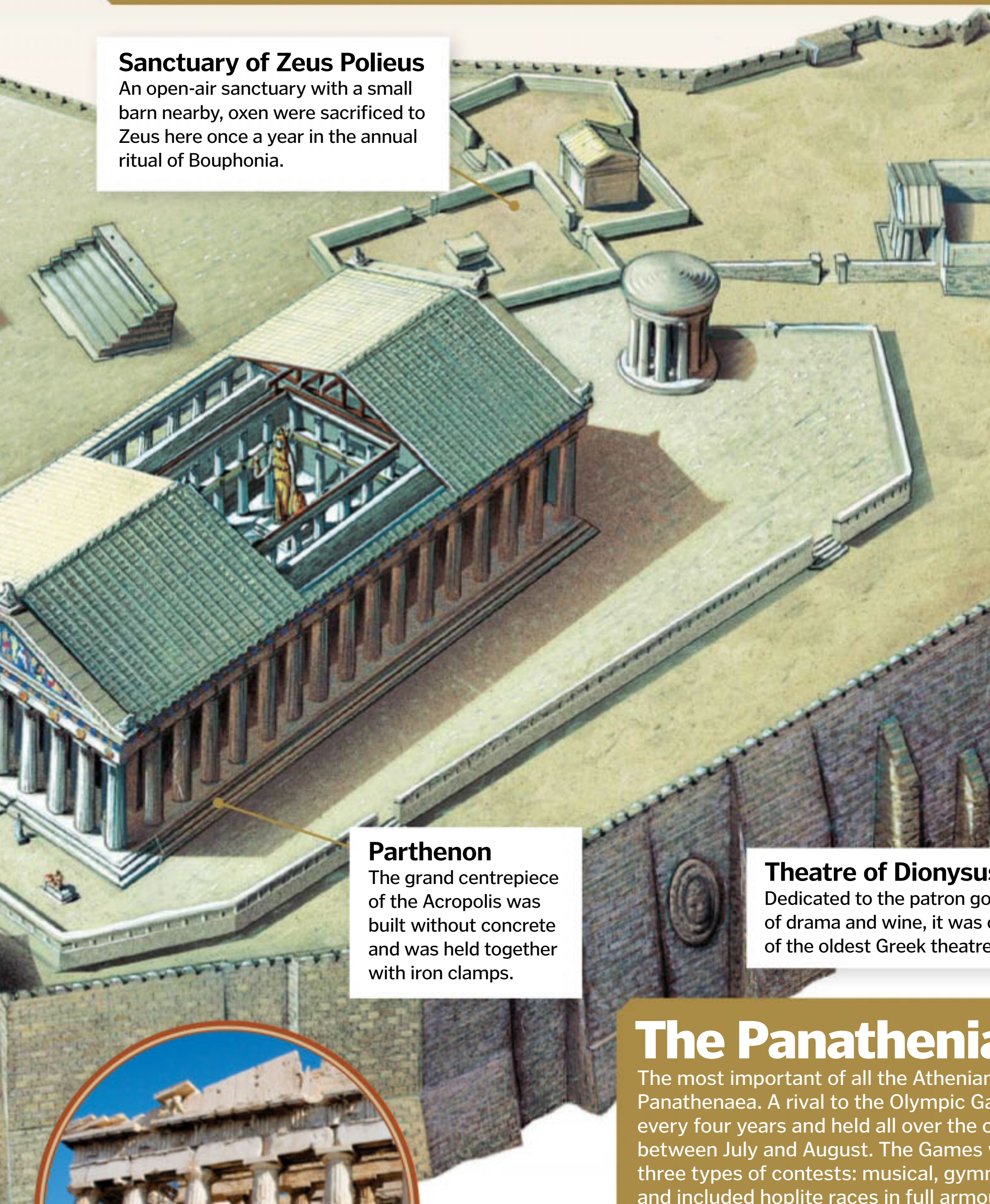
The popular Athenian general and statesman Pericles was the driving force behind the reconstruction of the Acropolis after it was destroyed by the Persians.

Pericles wanted the citadel to be larger and grander than ever before. The project was an expensive venture and Pericles skilfully used tributes paid to the city to fund it. Many of the finest architects and sculptors of the ancient world, along with hundreds of labourers, contributed.

Pericles is remembered as a hero of Athens and shortly after his death from the plague, the city lost the Peloponnesian Wars against Sparta and entered a period of cultural darkness.



Under Pericles' leadership the city entered a golden age of prosperity



Sanctuary of Zeus Polieus
An open-air sanctuary with a small barn nearby, oxen were sacrificed to Zeus here once a year in the annual ritual of Bouphonia.

Theatre capacity
17,000 spectators could cram into the theatre's tiers of stone seats to enjoy some of the most famous ancient Greek plays.

Parthenon
The grand centrepiece of the Acropolis was built without concrete and was held together with iron clamps.

Theatre of Dionysus
Dedicated to the patron god of drama and wine, it was one of the oldest Greek theatres.

The Panatheniac Games

The most important of all the Athenian festivals was the Panathenaea. A rival to the Olympic Games, it was celebrated every four years and held all over the city for around a week between July and August. The Games were based around three types of contests: musical, gymnastic and equestrian, and included hoplite races in full armour and pankration (a brutal mix of wrestling and boxing). The event was organised by ten administrators called the Athlothetai, and men, women and children all competed in the events, from professional athletes to freed slaves. The winners were mostly presented with valuable prize amphoras, which they often sold for coin. Champions gained so much money that they could make a career out of participating in these festivals.

The Games held a pentathlon including running, javelin, discus and long jump

483 BCE
Mining precious metals
Athens establishes silver mines, which allow Themistocles to create a fleet to defeat the Persians at Salamis.

468 BCE
Development of the theatre
Tragedian Sophocles writes plays for theatre, which become immensely popular.

447 BCE
Building the Parthenon
Construction begins on the Parthenon, a temple dedicated to Athena, the goddess of wisdom and war.

420 BCE
Atomic theory of matter
Philosopher Democritus hypothesises the existence of atoms and different types of matter.

Innovations and inventions

The ancient Greeks devised many clever mechanisms and systems that are still used today

From the Olympics to democracy, Greek civilisation had a huge impact on the West. The Babylonians may have created the first maps, but it was the Greeks who pioneered the study of cartography. Philosopher Anaximander drew up the first world map, which was divided into two sections: Europe and Asia. The Greeks also revolutionised the field of geometry with Pythagoras' theorem and the refined value of pi.

Before the Greeks, ancient civilisations blamed disease on the wrath of gods. While the Greeks still believed in divine retribution, physicians like Hippocrates observed patients suffering with conditions and recorded signs and symptoms. This helped to advance surgery, anatomy and public health. There was also progress in the knowledge of the natural world, with the differences in plants documented for the first time. Greek thinking also resulted in inventions like the buckle, metal anchors and the crane.

City-states like Athens were built to a set plan. Surveyors devised streets and squares with enough room for theatres, markets and temples. This is one of the first recorded instances of urban planning, and provided cities with space and facilities. Multiple urban areas were based around the Hippodamian Plan: a city in a rectangular grid – helpful for navigating and organising the streets for both economic and defensive reasons.

Perhaps the most obvious relic of ancient Greece today is its architecture. Ionic and Doric columns are still used on many neoclassical buildings around the world, such as the US Capitol building and the Arc de Triomphe.

Even after the fall of ancient Greece, its legacy lived on. The Roman Empire was inspired by Greek mythology and built upon many Greek ideas of geometry, astronomy and culture.

Other Greek inventions

Inventions we still use today, from the shower to the alarm clock

Alarm clock
They worked by using a dial to indicate the time, which would sound with the drop of pebbles onto drums.

Water mill
The water mill ground grain to produce rice, flour, lentils and cereals, important for feeding the population.

Odometer
This mechanical instrument measured distance and was used by the Romans to help build their roads.

Shower
The Greeks were the first to use piped water to shower themselves. The showers were fed by a plumbing system.

The Archimedes' screw

The physics of Archimedes' screw, an ingenious Greek invention for raising up water or grain

380 BCE
The Athens Academy
Plato opens the first Western higher learning centre to educate students on mathematics and science.

c.359 BCE
Invention of the catapult
An early stone-throwing siege machine is invented in 4th century BCE, and becomes a commonplace weapon in large scale conflict.

336 BCE
Alexander the Great
The Macedonian king Alexander spreads Greek language and culture through Asia via an expansive and formidable empire.

335 BCE
Aristotle's lyceum
Alexander's tutor founds a school to rival Plato's that lectures students on physics and biology.

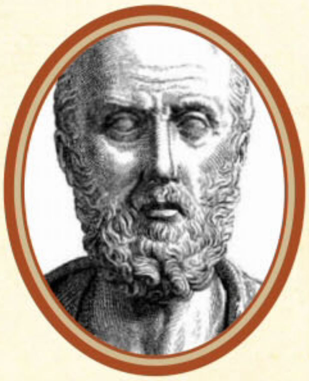
HELLENISTIC PERIOD

Great Greek minds

Meet some of the most prominent thinkers in all of ancient Greece

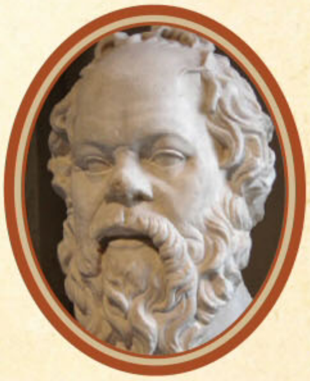
HIPPOCRATES

Hippocrates was one of the first to observe the effect diseases had on the body. He separated medicine from religion, and by recording what he saw – whether it was a pale face or dry skin – he helped develop methods to prevent and cure diseases.



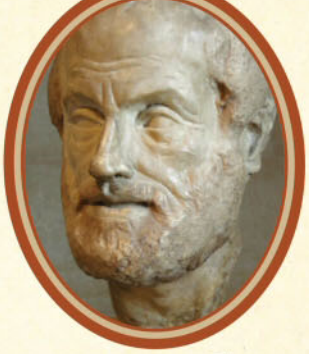
SOCRATES

Socrates was a renowned philosopher, and Socratic teaching concentrated on asking questions, fostering debate and forming ideas through conversation. The Socratic method is still used by educators today to encourage their students to think critically.



ARISTOTLE

The so-called father of logic wrote over 150 works and spoke on the topics of philosophy and biology like no other. He believed that existence was based on achieving personal happiness.

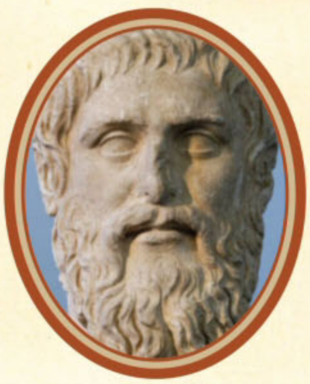


EUCLID

A leading mathematician, Euclid wrote 13 books known as *The Elements*, which collected 300 years worth of ancient ideas on geometry. Euclid made these earlier works accessible to many and it has become incredibly influential in teaching.

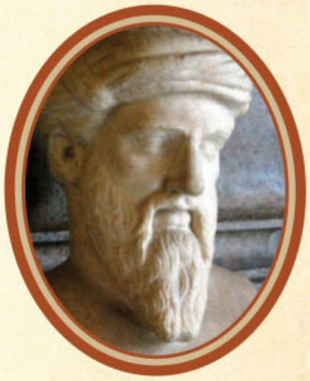
PYTHAGORAS

Known as the father of numbers, Pythagoras is world-renowned for his eponymous theorem for deducing the length of the third side of a triangle. Many works were published in his name by his loyal followers.



PLATO

The teacher of Aristotle was a student of Socrates who spread his mentor's teachings. He lends his name to the idea of Platonic love and founded the first higher learning institute in the West.



What the Greeks did for us

The legacy of ancient Greece in the 21st century

Olympics

Dedicated to Zeus, the Olympic Games first took place in 776 BCE.

Hippocratic oath

This sacred oath was written by Hippocrates and promises that a doctor will do everything they can to help their patient.

PEER JURY

The justice system and the concept of a trial were advanced in Athens.

Philosophy

The Greeks were the first to constantly question the world and develop new scientific methods of thought.

Theatre

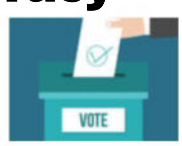
Both dramas and comedies were performed in front of audiences.

SPHERICAL EARTH THEORY

Pythagoras was the first person to propose that the Earth was a sphere after observing our round Moon.

Democracy

For a time, male Athenian citizens had equal political rights and freedom of speech.



A α
B β

Language

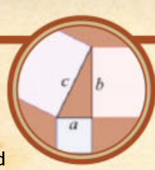
The ancient Greek writing system inspired the Latin alphabet and is still in use.

"City-states like Athens were built to a set plan"

c.300 BCE

Mathematical advancements

Mathematician Euclid writes *The Elements*, an influential collection of 13 textbooks on geometry, which included work on Pythagorean theorem.



c.250 BCE

Archimedes' screw

The great Greek polymath Archimedes conceives the Archimedes' screw, just one of his many inventions.

238 BCE

Syracuse theatre

A popular Greek theatre is expanded significantly into one of the largest known in the ancient world.

146 BCE

Roman Greece

The Romans invade Greece. Impressed by Greek architecture, cities become tourist attractions and many customs are copied.

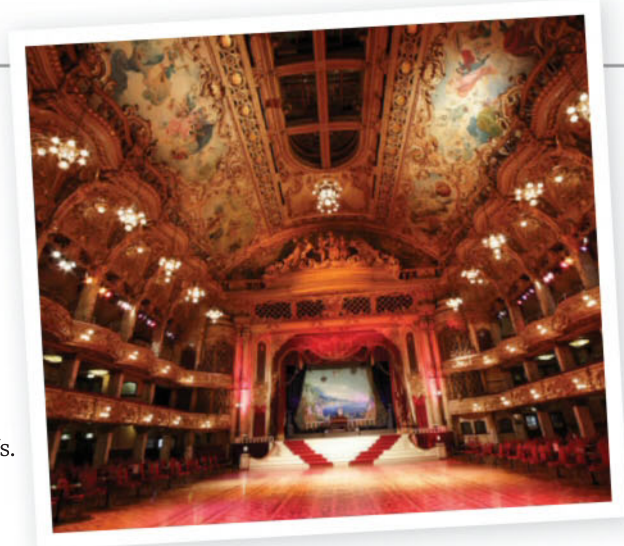
Ballroom floors

How sprung underlays dampen impacts and absorb the shocks of dancing feet

Both the surface and the underlay of sprung dance hall floors are specially designed to prevent injury and withstand dancing shoes. Metal coils were originally used, but these were found to be too bouncy for ballet and contemporary artistic dance, so they were replaced with rubber pads and wooden panels. These act as a spring to the top layer, and as the floor absorbs more of the shock, less pressure is put on a dancer's body after a jump.

A number of different floors can be fitted, from wooden to vinyl, depending on the dance style. For example, floors for tap dancing are typically more durable, to cope with shoe scuffs.

The Blackpool Tower Ballroom in the UK contains one of the most famous sprung floors in the world. Opened in 1894, the 1,137-square-metre floor – made of 30,602 blocks of mahogany, oak and walnut – continues to host dance tournaments to this day.



The Blackpool Tower Ballroom originally opened in 1894, but required restoration to its former splendour following a fire in 1956

Wooden sprung floors

How wooden dance floors help put a spring in dancers' steps

Russian nesting dolls

The little-known origins of the now universally recognised and iconic wooden figurines

On average, the sets contain three to 12 dolls

Russian nesting dolls have been a part of Russian culture since the late 19th century. They are also called matryoshka – a name with strong ties to a motherly figure in Russia – and the idea first came from an 1896 exhibition in Moscow. One of the toys on show was a wooden Japanese doll based on Fukuruma, which held many layers of miniature versions of the figure inside a larger outer shell. It inspired local craftsmen Sergey Malyutin and Vasiliy Zvyozdochkin to take the idea and develop it into a design that is now known around the world.

The dolls are commonly made of one piece of lime wood and decorated with tempera or oil paints. They are carved from a cylindrical wooden piece, using a turning lathe and woodcarving knives. The smallest doll is the only solid member, and the carver will ensure that the other hollow shells all fit neatly inside one another.

Matryoshka dolls often depict a Russian woman in traditional dress, and symbolise the idea of family and motherhood in Russia. They are still a popular child plaything as well as an enduring symbol of Russian culture and art.

Hagia Sophia

Explore the innovative design and rich history of Turkey's domed wonder

Once a cathedral, then a mosque, and now a museum, the Hagia Sophia is an architectural jewel that has stood for 1,400 years. Its construction began in the 6th century CE, when Istanbul was known as Constantinople, the capital city of the Roman Byzantine Empire.

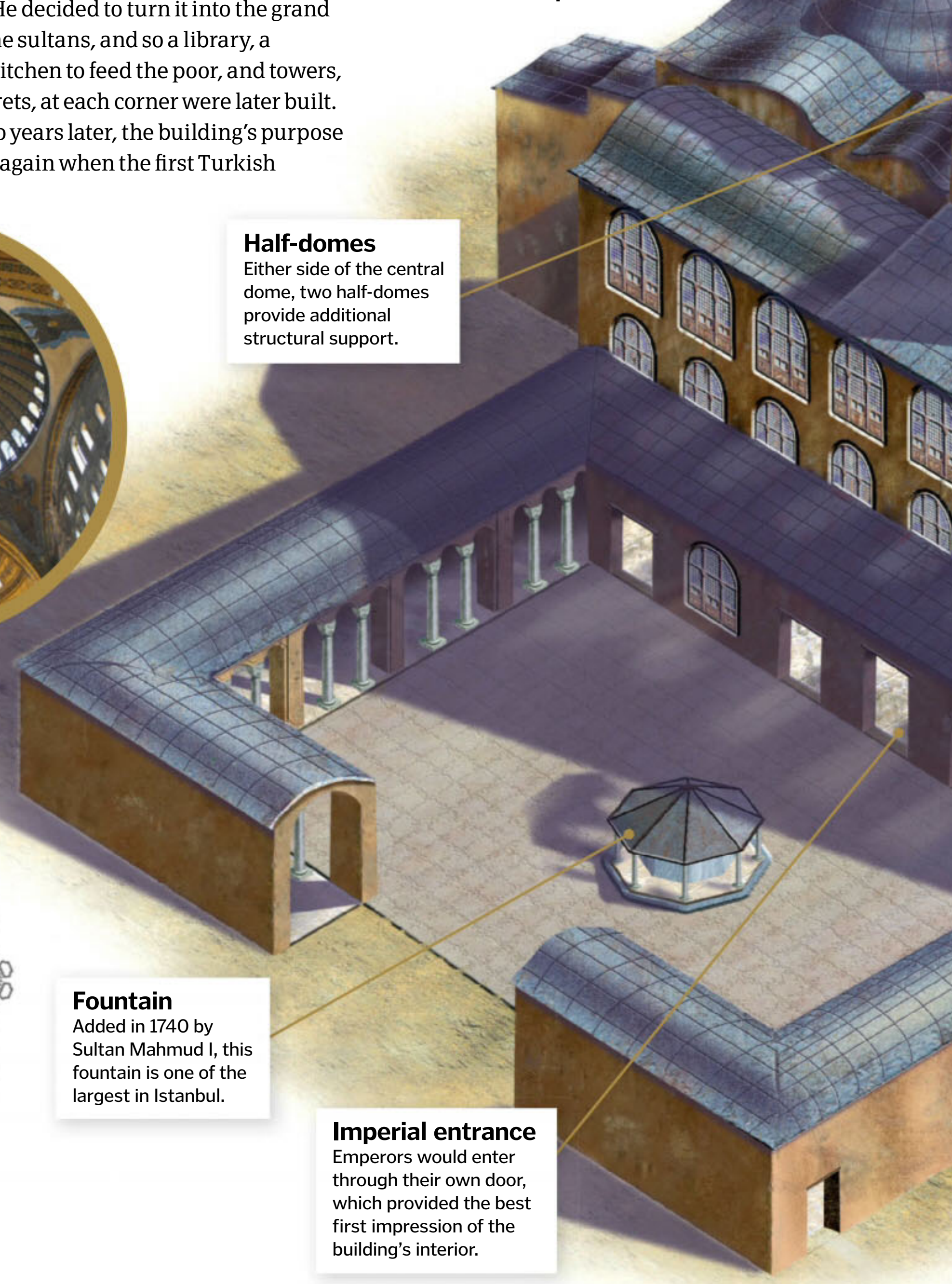
Its site had previously been home to the Magna Ecclesia, meaning 'Great Church' in Latin, which was burned down during riots in 404 CE, and then another church, which was destroyed during the Nika Revolt in 532 CE. At that time, Emperor Justinian I was the ruler of the empire, and once the revolt against him had been suppressed, he ordered a grand new cathedral to be built. He commissioned Anthemius of Tralles, a mathematician and physicist, and Elder Isidore of Miletus, a professor of geometry and mechanics, to lead the project, and although neither had much architectural experience, they managed to design a domed structure that was incredibly innovative for its time. Less than six years later, construction of the world's largest cathedral was complete, a title it retained until the Seville Cathedral surpassed it 1,000 years later.

By the time the Byzantine Empire ended in 1453, the Hagia Sophia had fallen into disrepair, but when Mehmed II, the Sultan of the new Ottoman Empire, saw it he was greatly impressed. He decided to turn it into the grand mosque of the sultans, and so a library, a fountain, a kitchen to feed the poor, and towers, called minarets, at each corner were later built.

Almost 500 years later, the building's purpose changed yet again when the first Turkish president came into power. He ordered for the Hagia Sophia to be turned into a museum, and in 1935 it opened its doors to the general public, allowing them to explore one of the greatest surviving examples of Byzantine architecture for themselves.

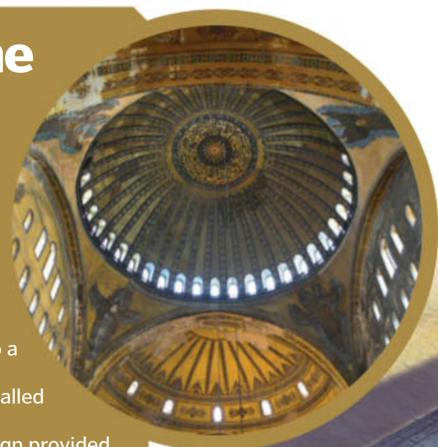
Beneath the dome

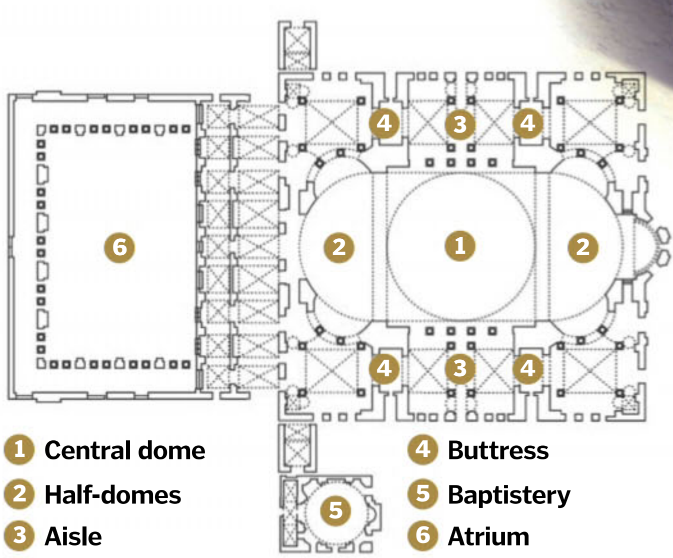
An innovative design shaped by the Byzantine and Ottoman Empires



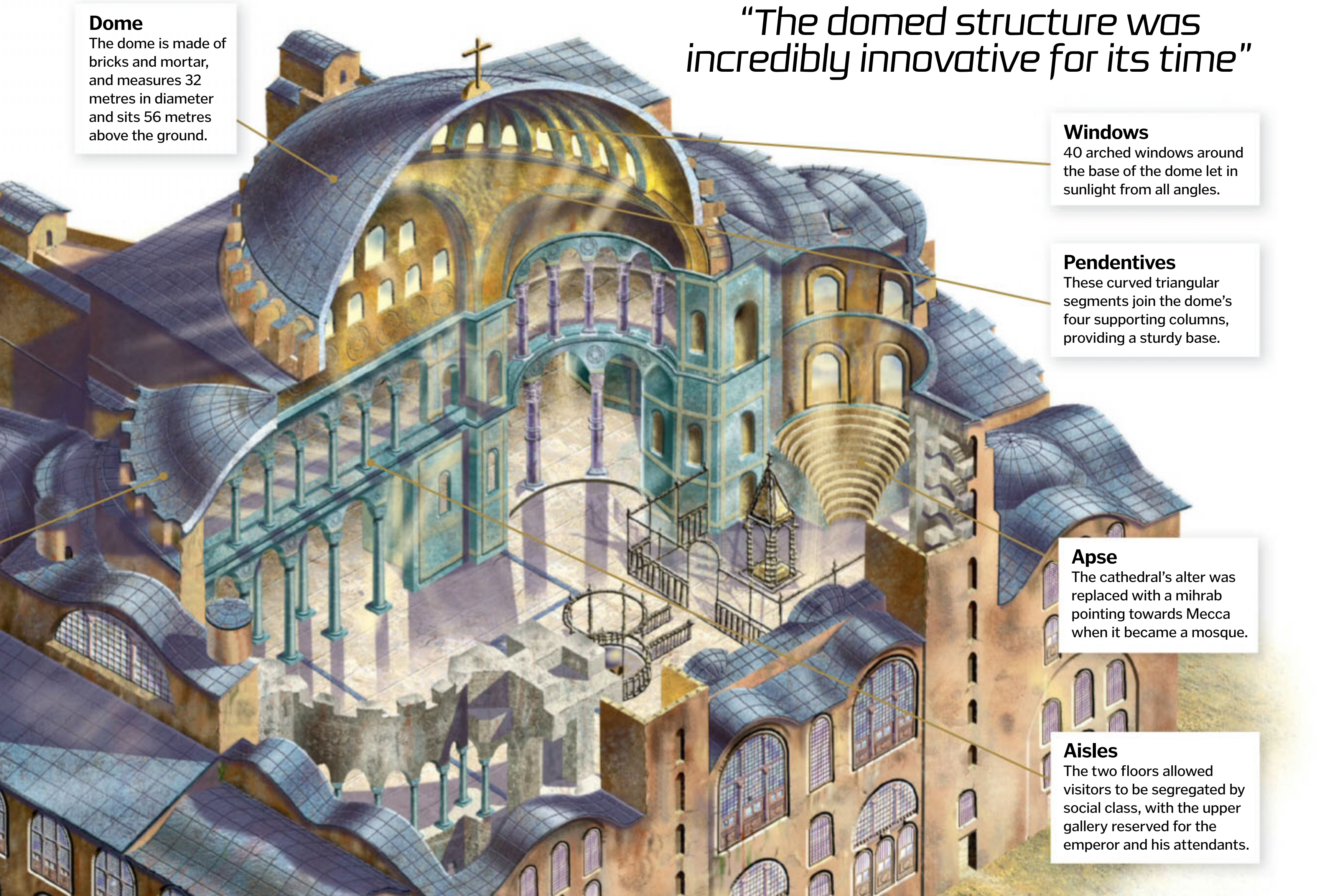
A daring dome

The innovative domed roof of the Hagia Sophia caused problems during the building's construction, as the walls struggled to support its enormous weight. The solution was to distribute the weight downwards by placing it on four columns, which worked brilliantly until an earthquake struck in 558 CE. The original dome collapsed completely and so a new one had to be built, this time with curved triangular segments called pendentives placed between the supporting columns. The new design provided an incredibly sturdy base for the dome, which still stands to this day, and it has been copied by countless architects ever since.





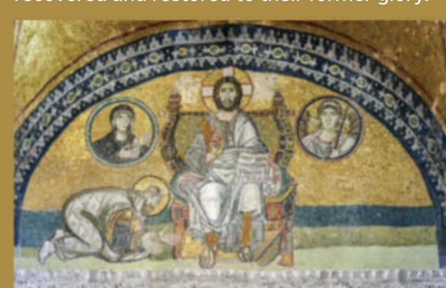
"The domed structure was incredibly innovative for its time"



The name Hagia Sophia is Greek for 'holy wisdom'

Masterful mosaics

During its years as a Roman cathedral, the Hagia Sophia was decorated with ornate mosaics depicting emperors and religious figures, but not all of them can still be seen today. In 726 CE, Emperor Leo of Isaurian ordered religious mosaics to be destroyed, fearing the people would worship the images. His successors soon added more, but some were shipped to Venice in 1204, and the rest were covered with plaster and paint when the building became a mosque. However, since 1931, many of these works of art have been recovered and restored to their former glory.



The mosaic located above the imperial entrance dates back to the 9th or 10th century

Windmills

Find out how these towers have helped harness wind power throughout history

It is thought that the windmill was invented around 1,500 years ago. Historians are still unsure exactly where the first one was constructed, but it is believed that it was either in ancient China or ancient Persia.

The first windmill mechanisms used millstones powered by sails that rotated a drive shaft to pump water or mill cereal. They became an integral part of ancient agriculture and were also used in sawmills and to help with irrigation and drainage.

The first windmills turned on a vertical axis. Later versions revolved horizontally, which was found to be a more efficient process. Tail fans were also added to later models to automatically move the sails in the direction the wind was blowing.

To remedy variable wind speeds, modern windmills utilise overspeed controls to turn the mechanism away from the wind if the gusts are too powerful for the sails to handle. Before the invention of windmills, grounding corn, pumping water and cutting lumber was done by hand. Windmills sped up and increased the efficiency of the process significantly, having a dramatic impact on the world's agriculture and economy.

Inside a thatched smock mill

How a windmill uses wind power to mill grain

1. Revolving cap
The cap of the mill rotates to face whichever way the wind is blowing, increasing rotation speed.

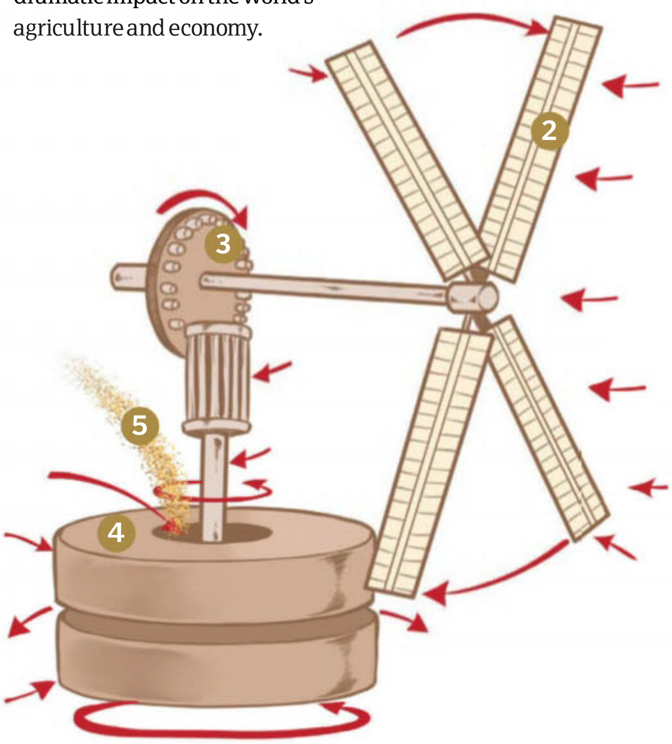
2. Sails
The lattice sails move anti-clockwise, turning the mechanism inside in a clockwise direction.

3. Brake wheel
The sails catch the wind and turn the horizontal wind shaft, which in turn revolves the largest cog, the drive gear.

4. Dual millstones
The movement of the drive gear turns a vertical shaft that powers a millstone.

5. Feeding the grain
The grain is fed into the two millstones by a hopper. One millstone is still while the other rotates.

6. Grain to flour
The bottom floor is called the meal floor and is where the flour, barley or oats are collected.



Why did windmills fall out of use?

The use of windmills has declined in the modern world. This is primarily down to the introduction of steam power in the Industrial Revolution. This reduction only became even greater than before when electricity came into common use.

Today, windmills are mainly listed as heritage sites or have fallen into disrepair. Rather than grinding grain, today's windmills take the form of wind turbines and are one of the world's leading renewable energy sources. Moreover, simple wind pumps have been around since ancient times and are still commonly used both for draining wetlands and obtaining groundwater in areas short on drinking water.

These unique buildings have been replaced by modern technologies

BRAIN DUMP

Because enquiring minds need to know...

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MEET THE EXPERTS

Who's answering your questions this month?

Laura Mears

Laura studied biomedical science at King's College London and has a master's from Cambridge. She escaped the lab to pursue a career in science communication and also develops educational video games.

Alexandra Cheung

Having earned degrees from the University of Nottingham and Imperial College London, Alex has worked at many prestigious institutions, including CERN, London's Science Museum and the Institute of Physics.

Tom Lean

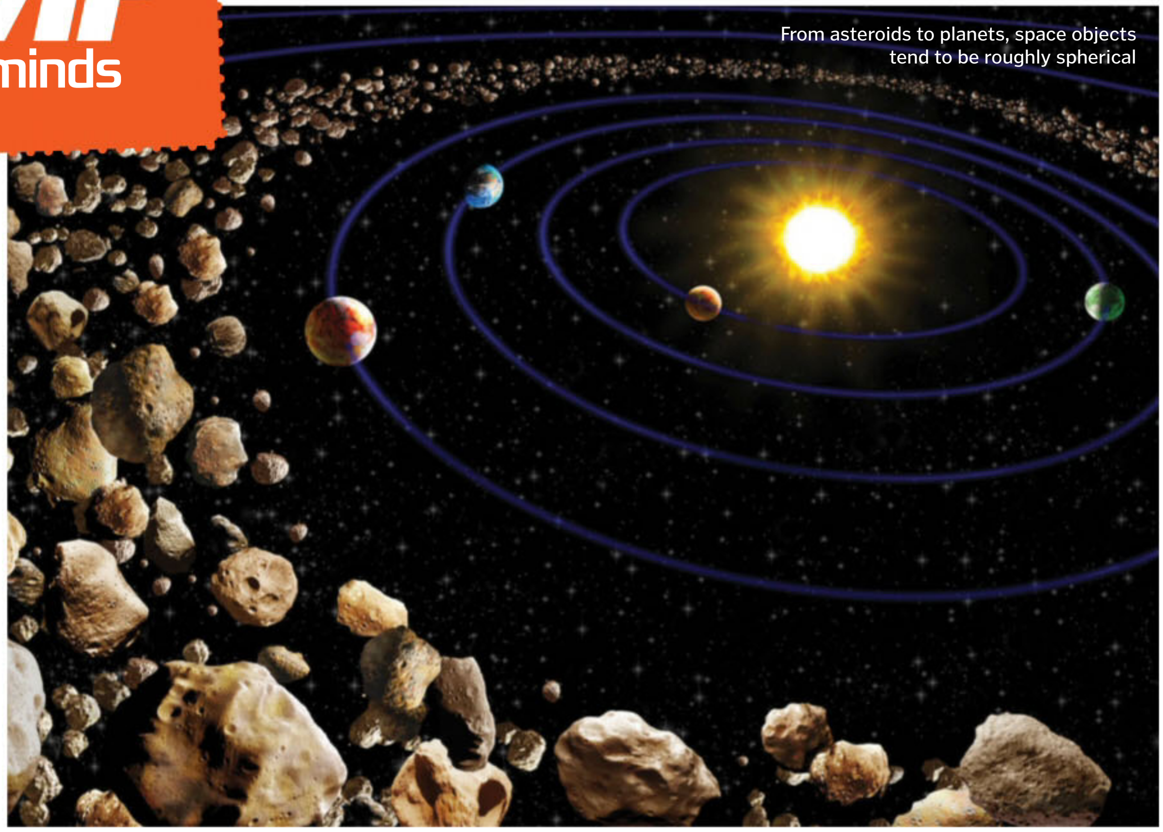
Tom is a historian of science at the British Library where he works on oral history projects. He recently published his first book, *Electronic Dreams: How 1980s Britain Learned To Love The Home Computer.*

Shanna Freeman

Shanna describes herself as somebody who knows a little bit about a lot of different things. That's what comes of writing about everything from space travel to how cheese is made. She finds that her job comes in very handy for taking part in quizzes!

Joanna Stass

Having been a writer and editor for a number of years, **How It Works** alumnus Jo has picked up plenty of fascinating facts. She is particularly interested in natural world wonders, innovations in technology and adorable animals.



From asteroids to planets, space objects tend to be roughly spherical

Why are there no square objects in space?

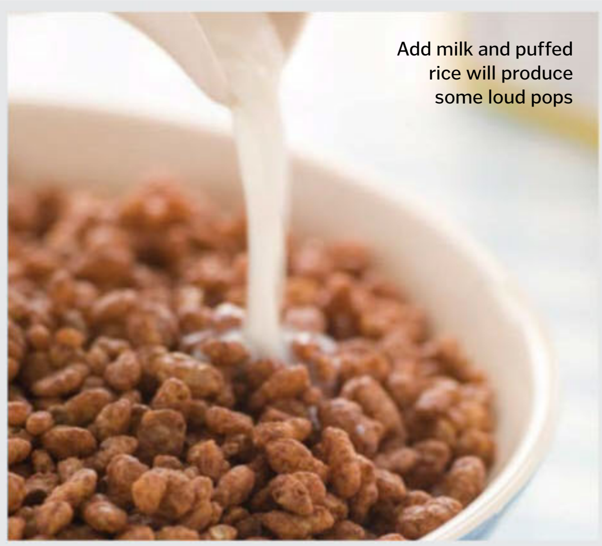
Paddy Whimslow

Large square and cubic objects don't occur naturally in space as the effect of gravity tends to squeeze objects into spherical shapes. A planet forms by picking up surrounding dust, gas and debris – a process known as accretion. Gravity pulls this matter together towards the centre of the planet, and the most effective way for the matter to accommodate this pull is to form a sphere. Likewise, the strong gravitational pull created by a star's dense core moulds the gas on its outer surface into a sphere. Angular objects do exist in space, such as broken fragments of rock resulting from collisions, but these would be unlikely to produce anything approximating a square or cube. The only naturally occurring cubes or squares are crystals such as pyrite or salt, although these are relatively small. Any larger square objects point to the work of humans – or possibly that of another intelligent life form. **AC**

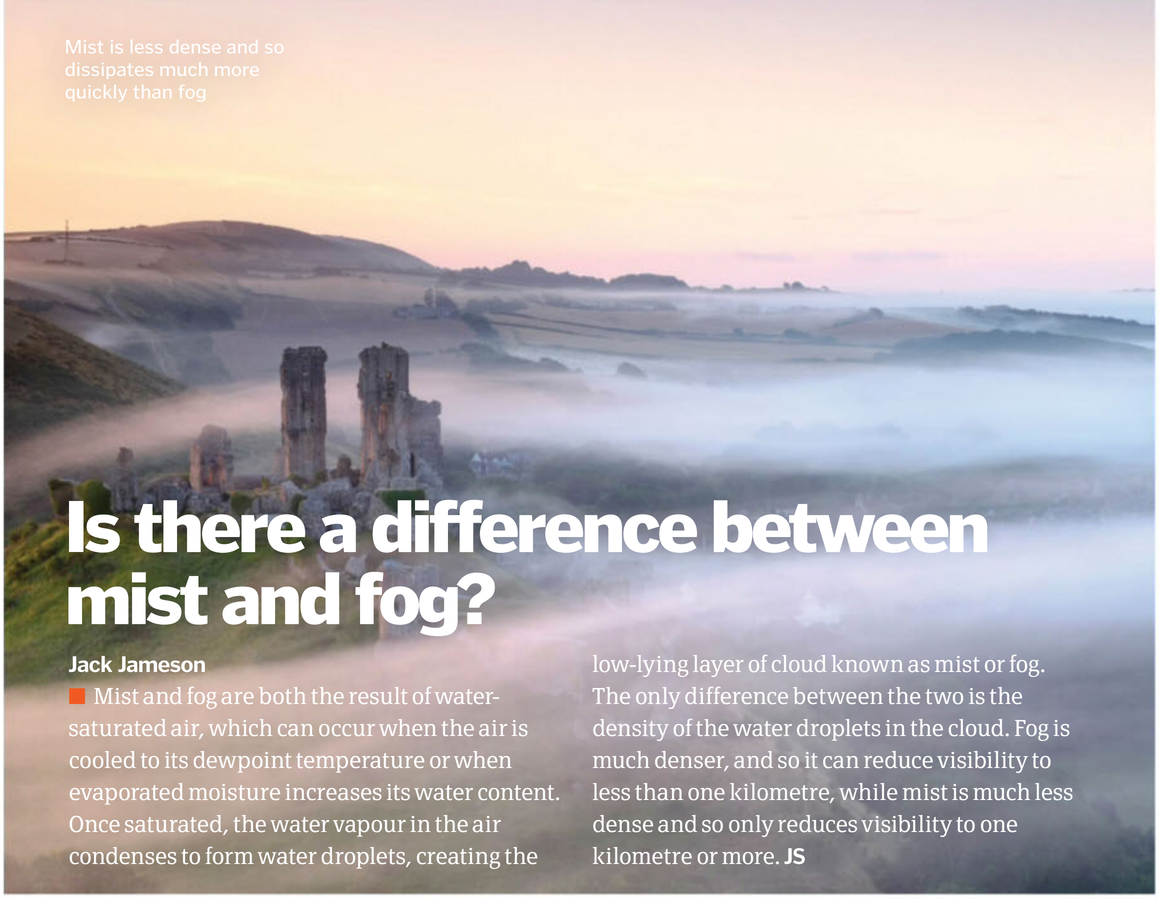
Why do some breakfast cereals pop?

Jordan Fairclough

The crackling you hear when you pour milk on certain cereals, including crispy rice, is the sound of the tiny walls that give them structure snapping. Puffed cereals are made by heating rice, wheat or corn to high temperatures, making moisture inside the grain expand to form little bubbles. Meanwhile, the heat causes the starches around these bubbles to form strong bonds. The result is a network of little pockets of air sealed off by very thin, brittle (and therefore crunchy) walls. As the cereal absorbs milk, this puts the air trapped in these cavities under pressure, causing the walls to eventually cave with a 'pop'. **AC**



Add milk and puffed rice will produce some loud pops

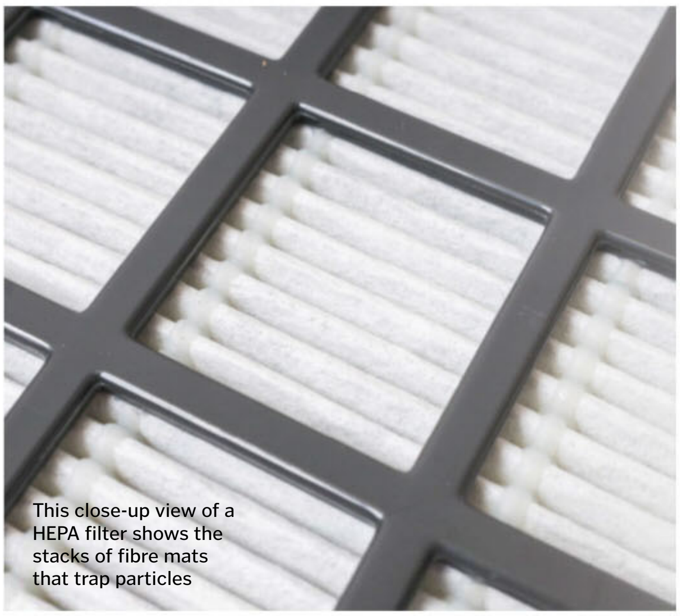


Mist is less dense and so dissipates much more quickly than fog

Is there a difference between mist and fog?

Jack Jameson

Mist and fog are both the result of water-saturated air, which can occur when the air is cooled to its dewpoint temperature or when evaporated moisture increases its water content. Once saturated, the water vapour in the air condenses to form water droplets, creating the low-lying layer of cloud known as mist or fog. The only difference between the two is the density of the water droplets in the cloud. Fog is much denser, and so it can reduce visibility to less than one kilometre, while mist is much less dense and so only reduces visibility to one kilometre or more. **JS**



This close-up view of a HEPA filter shows the stacks of fibre mats that trap particles

How does an air purifier work?

Curtis Jewell

Air purifiers work by removing particles from the air. The gold standard are HEPA air filters; this stands for High Efficiency Particle Arrestance. They are used in science labs to keep the air as clean as absolutely possible, and to qualify for HEPA status, they have to remove 99.97 per cent of particles greater than a third of a micrometre in size. They work by trapping particles in a mat of densely arranged fibres. There are also ionising purifiers, which work by attracting dust using electrical charges, UV-light purifiers, which aim to kill bacteria in the air, and activated charcoal filters, which cling to odours and chemicals. **LM**

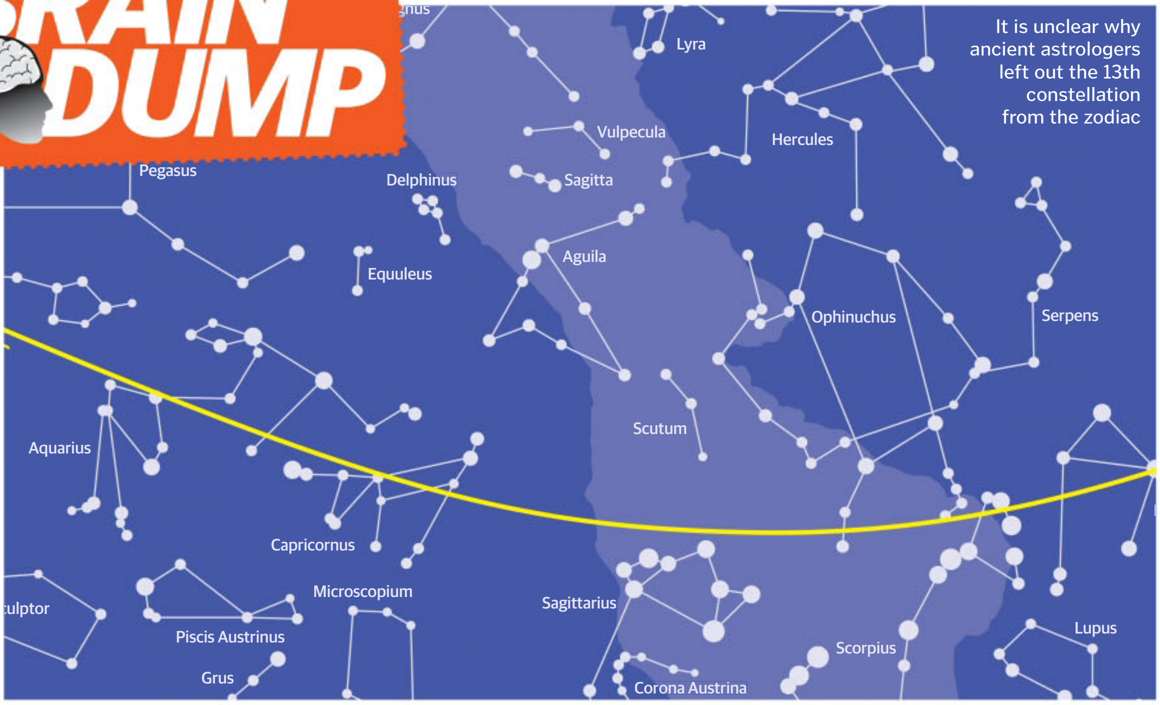
How are artificial sweeteners made?

Wendy Cole

This varies depending on the sweetener. Saccharin – discovered after scientists working with the molecule noticed their food getting sweeter – is made by oxidising a chemical called o-toluenesulfonamide. Aspartame is made differently. Bacteria are used to produce aspartic acid and phenylalanine. These are then purified and mixed with methanol to modify their chemical structure. The two molecules are then mixed together to form crystals, and then mixed with vinegar to make aspartame. **LM**

The chemical structure of artificial sweeteners tricks our tongues into tasting sugar

BRAIN DUMP

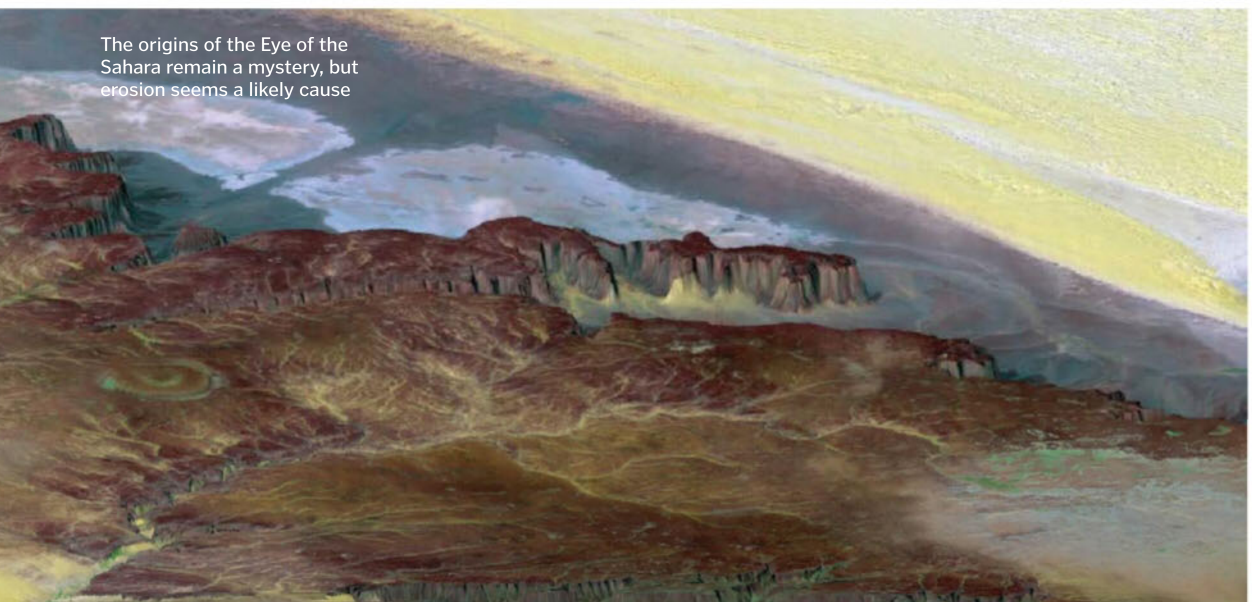


It is unclear why ancient astrologers left out the 13th constellation from the zodiac

Is it true there is a 13th zodiac constellation?

Victoria Ludlow

A 13th zodiac constellation, Ophiuchus, exists between Scorpio and Sagittarius, but was left out of the zodiac by ancient astrologers. Over 3,000 years ago Babylonians invented the zodiac – a circle of constellations based on the apparent path that the Sun takes over the course of the year. The constellation behind the Sun when someone was born determined their 'star sign'. Perhaps because having 12 constellations matched up better with their 12 month calendar, the Babylonians left out Ophiuchus. Anyone born between 30 November and 18 December is therefore an Ophiuchus – although astrological predictions have no scientific grounding. **AC**



The origins of the Eye of the Sahara remain a mystery, but erosion seems a likely cause

What's the Eye of the Sahara?

Phoebe Shephard

The Eye of the Sahara – also known as the Richat Structure – is a huge circular formation located in Mauritania, Africa. Spotted more easily from space, and once thought to be a crater, it forms a bull's eye in the Sahara Desert, and has a diameter of 40 kilometres. However, recent geological studies suggest it is actually a result of erosion rather than some kind of meteorite impact structure. Some scientists believe the erosion is a consequence of Pangaea being ripped apart by plate tectonics more than 100 million years ago. Others believe that it is the remains of the lost city of Atlantis. **SB**

FASCINATING FACTS

Are there laws that apply on the ISS?

According to an intergovernmental agreement, any equipment or personnel on board the ISS is the legal responsibility of the country or continent that supplied it, and so it is governed by that nation's laws. **JS**

If someone commits a crime on the ISS, their own nation's laws apply

What's the dust inside airbags for?

The white powder found inside older airbags is either cornstarch or talcum powder. It's used to lubricate the bag, helping it unfold quickly. **AC**

An airbag inflates in less than 1/20th of a second

Are in-ear headphones bad for your health?

They're not as good at cancelling out background noise, so there can be the temptation to turn the music up, which has the potential to damage your hearing. **LM**

On-ear headphones block out other noises, but the in-ear kind are not as effective at doing this


It's very likely that the legend of the Trojan horse is purely mythical

Did the legend of the Trojan horse really happen?

Emma Kepler

■ It's unlikely that the legend of the Trojan horse really happened. Mentioned in Homer's *Odyssey* and the *Aeneid* (a Latin epic poem), the classic tale describes how Greek soldiers built – and hid in – a large wooden horse during the Trojan wars. Transported into the city of Troy by the Trojans – who assumed it was a gift – the Greek soldiers climbed out and opened the gates after a ten-year siege – so the tale goes. However, scholars and classicists believe it was a myth, because there is archaeological evidence to show that the city was actually burned down. It's not known for sure whether the legend is true, partially true or completely made up, but the general consensus is that it did not happen. **SB**

What was the point of a standard-bearer?

Rosie Hamilton

■ A Roman standard was a pennant, flag or banner attached to a pole that identified a particular Roman legion. Not only was it a formal symbol of a military unit, but it was also a metaphorical symbol of honour. The standard-bearers played a vital role during battle by giving members of the unit a visual signal as to where the unit was, should they be separated. They may have also ensured troops kept their correct positions by lowering, raising or waving the standard to indicate what move the troops should make next, or to change formation or tactic. **SB**


The standard-bearer carried a symbol of Roman honour into battle

Does animal saliva kill germs?

Miriam Elliot

■ Since very few studies have been carried out on the subject, it's hard to know for sure, but limited research suggests that antimicrobial properties exist in dog saliva. These properties include lysozyme, an enzyme that kills certain bacteria; histatins, which are proteins that repel infections and help skin cells to close over a wound; and nerve growth factor, a protein that significantly reduces healing time, although the effectiveness of this property is questionable. **SB**


Animal saliva contains antimicrobial properties that can potentially kill germs


Squashed or damaged nerves can send bursts of signals that feel just like pinpricks

Why do we get pins and needles?

Jason Appleby

■ Pins and needles is also known as paraesthesia, which literally means 'irregular sensation'. It happens when the sensory nerves are squashed or damaged. These nerves are responsible for relaying information about pressure, temperature and pain to the brain. When they are disrupted, signals can be sent by mistake. If you cut off the blood supply to an arm or a leg by sitting at an awkward angle, the nerves are temporarily starved of oxygen and stop working. When the blood comes back, and the nerves wake up, they can send bursts of signals that feel like prickling or burning. The amount of prickling depends on the length of the nerve. **LM**

Can an F1 car create enough downforce to stick to the ceiling?

Julian Pottle

■ In theory it could do, but the car's components would only allow it to run upside down for a few seconds. Their wings are designed to create negative lift as air flows over them, pushing the car's tyres down for better steering. One study calculated that at speeds above 180 kilometres per hour, the downforce created by an F1 car would be great enough to overcome gravity, allowing it to drive on the ceiling. **AC**


Downforce gives F1 cars more traction, helping them adhere to the road when racing around corners

BRAIN DUMP

USB A, Mini USB and Micro USB are the most common USB connector sizes

Why are there different sizes of USB connectors?

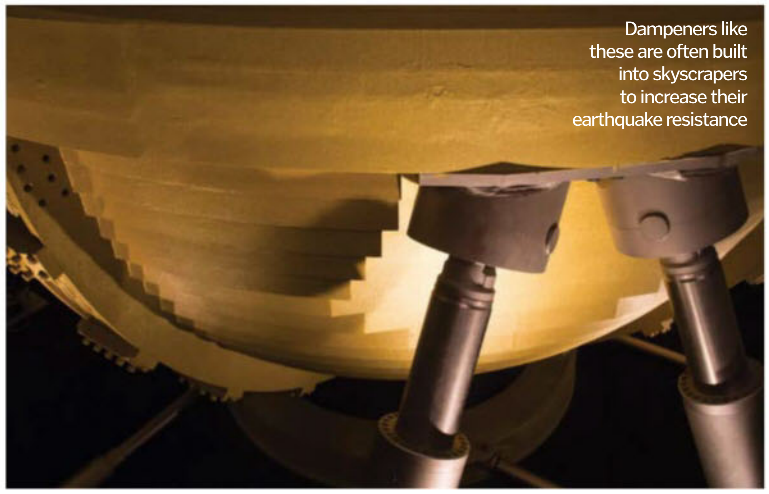
Kimberly Alden

■ In the past there were so many different types of computer connectors for different devices that it was quite confusing for people to know which one to use. USB was originally developed as a universal connector for printers, joysticks, scanners and anything else you might want to connect to a computer. However, the original USB connectors were too big for the smaller gizmos that have come along since, like MP3 players and smartphones, so smaller ones were developed to fit them. Sometimes particular manufacturers also develop their own USB connectors, so USB has become much more confusing than its inventors intended! **TL**

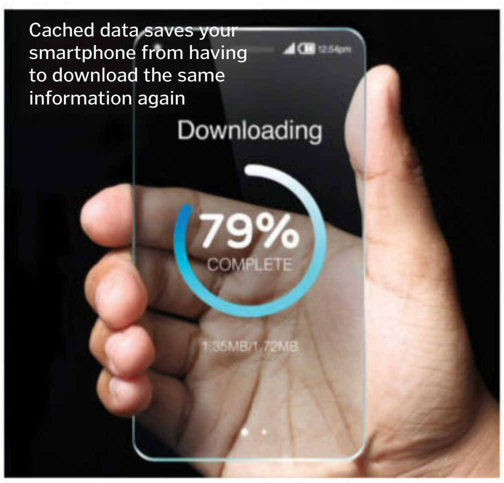
How does an earthquake-resistant structure work?

Niall Evans

■ Having a sturdy structure that won't easily shake apart is an important starting point, but strength isn't everything in making something earthquake-resistant. Structures can be engineered to make them more flexible or built with features that absorb the energy of seismic waves. It's also about choosing the right materials; steel is more flexible than brick, for example. Rather than building on rigid foundations, structures can also be built on seismic dampeners, which are shock absorbers that lessen the effects of earthquakes on structures, or built on bearings, so the entire structure can slide around rather than break apart in a tremor. **TL**



Dampeners like these are often built into skyscrapers to increase their earthquake resistance



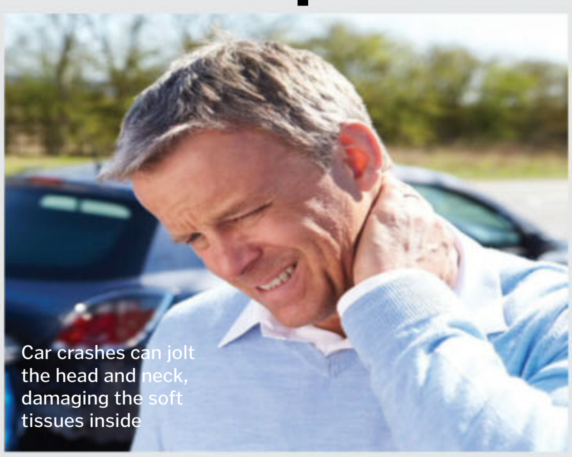
Cached data saves your smartphone from having to download the same information again

What is 'cached data' on my phone?

Pete Sampson

■ Cached data is information from apps and websites that gets stored on your smartphone. Whenever that data is needed again it can simply be accessed from the smartphone's cache rather than being downloaded once more. It's often quite useful as it saves time and data transfer costs, but it can be problematic if the cache contains out of date information or uses up too much of your smartphone's memory. **TL**

What is whiplash?



Car crashes can jolt the head and neck, damaging the soft tissues inside

Maria Cortez

■ Whiplash is an injury most commonly associated with car accidents but it can happen outside of a vehicle too. It is essentially a sprain to the muscles and soft tissues of the neck, and occurs when they are stretched beyond their normal range of motion. This causes damage, which can result in pain, stiffness, muscle spasms and headaches. The injury usually resolves itself on its own, and although it may be uncomfortable to move, neck braces aren't usually recommended. Instead, the advice is to stay mobile and gently strengthen the tissues again. **LM**

FASCINATING FACTS

Do fan ovens really cook food more evenly?

Nick Baker

■ Normal ovens, without a fan, are hotter at the top because hot air rises. Fan ovens circulate the hot air, keeping the whole oven near an even temperature, which cooks the food faster and more evenly. **TL**

The first description of a lemon appeared in the early 10th century

Are lemons not naturally occurring fruits?

Priscilla Bedford

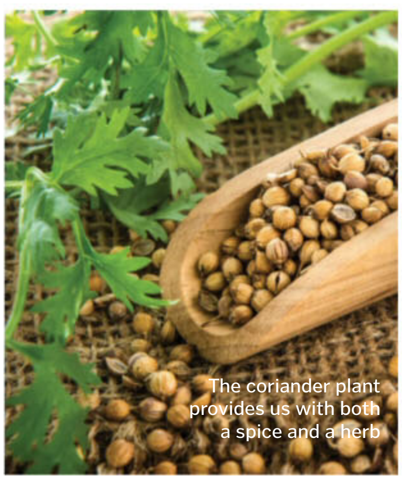
The lemon is what is known as a hybrid fruit as it is derived from two other fruit species. A study conducted by Chinese researchers and published in the *Journal Of The American Society Of Horticultural Science* in 2010, found that lemons are a cross between citron and sour orange, with sour orange itself being a hybrid of two other fruits. However, it is not known whether this cross-breeding occurred naturally or whether it was the result of human intervention. In fact, not very much is known about the origins of the lemon at all, although it is believed to have first been grown in Asia. **JS**

How does haptic technology work?

Paul Oakley

Haptics add a sense of touch to interaction with technology by giving some sort of physical feedback that you can feel. At its simplest, it can be like your smartphone vibrating when you press a button on its screen. At its most advanced, it can let you feel like you are touching computer-generated objects. Wearing haptic gloves and virtual reality goggles, for example, allows the computer to track your hands as you move them within a virtual reality simulation. If you 'touch' something in the simulation, vibrating motors or inflatable air pockets in the gloves give you some sort of feedback you can feel through your hands. **TL**

Haptic gloves allow you to feel like you're touching things in virtual reality



The coriander plant provides us with both a spice and a herb

What is the difference between a herb and a spice?

Hannah Rankin

Herbs and spices are both plant-based products that add flavour to our food, but there is one thing that separates them: the part of the plant they come from. Herbs come from the green, leafy part of plants, and so are often more flavourful when fresh, while spices can come from any of the other parts, such as the root, stem, seed, fruit, flower or bark, and are usually dried to preserve their flavour. This means that some plants give us both herbs and spices. For example, the leaves of the coriander plant are a herb, but the dried seeds are a spice. **JS**

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BOOK REVIEWS
The latest releases for curious minds

Eureka

Science explained through some amazing infographics

- Author: **Tom Cabot**
- Publisher: **William Collins**
- Price: **£20 / $24.95**
- Release date: **Out now**

Science textbooks can be boring. Pages of text broken up by the odd technical diagram quickly become tedious, and unless you learn easily through the written word, you may find yourself switching off after a few paragraphs, let alone a few pages. But not all science books are like that, as *Eureka* elegantly proves.

The front of the book suggests that it is filled with infographics – the kind of thing you see on blogs all the time, with simple images and big numbers giving you a ton of information quickly. In reality, it's really more of a halfway point between these simple graphics and a more in-depth textbook, and we have to say that the balance is great.

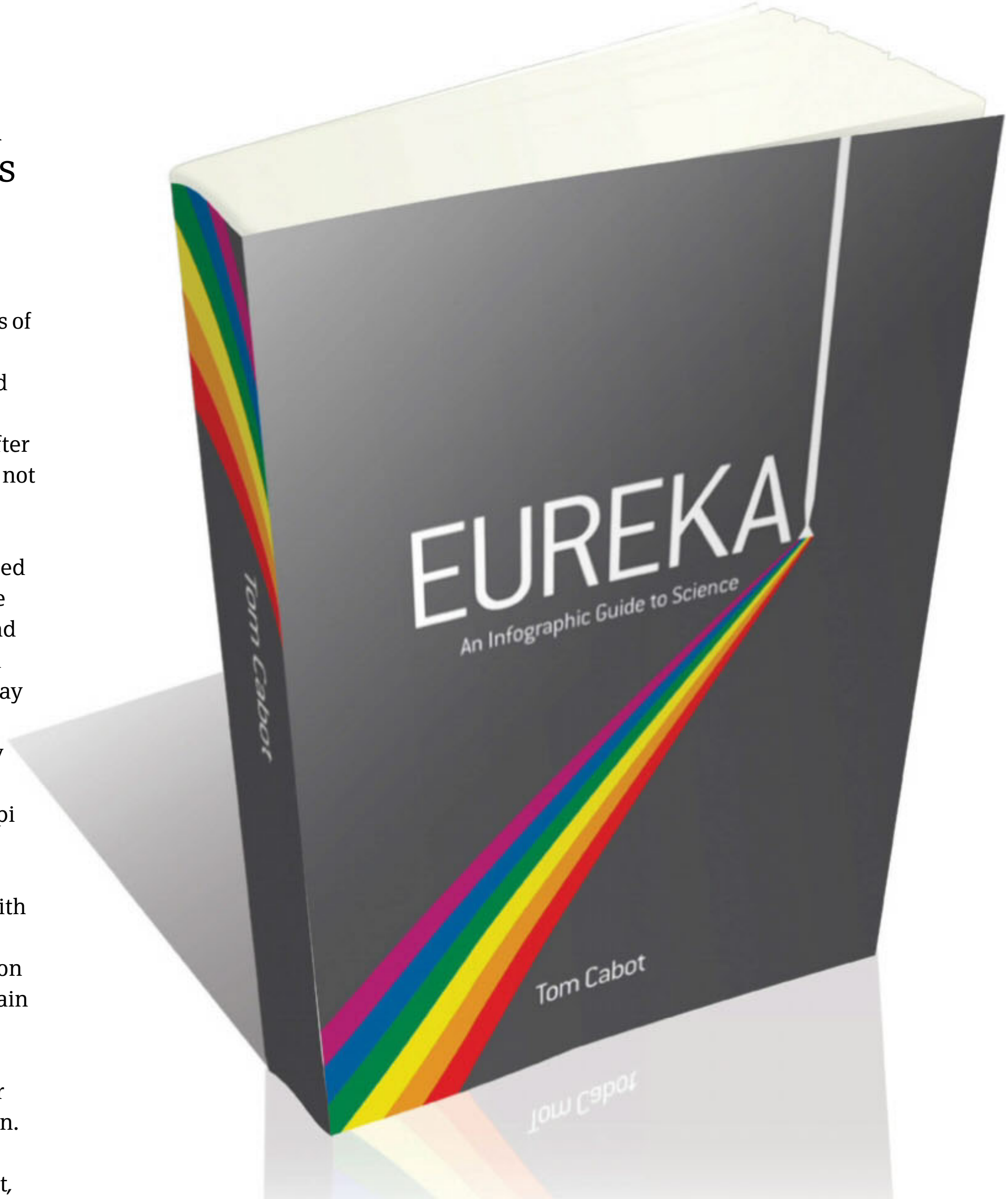
While there are some very simple pages (pi is listed to 1,001 places on one double-page spread, with each digit a different colour), others cover expansive or complex topics with a mixture of diagrams and text. The Earth's atmosphere, for example, uses a combination of graphs, imagery and infographics to explain how the different layers work.

There are hundreds of topics covered in the 240 pages, each grouped into one of four categories – Universe, Earth, Life and Human. Everything from human emotion to nuclear fission is explored through graphics and text, and for the most part, everything is explained in sufficient detail and in language that's easy enough to understand.

We found this book was best read in snippets – flicking through and finding topics that interested us was more enjoyable than reading cover to cover, and this will certainly be a book you keep returning to for a quick read.

If there's one downside to the graphical presentation style, it's that in certain cases the text can be small and difficult to read. With so much to fit on the page, the text size has clearly been the compromise, resulting in most letters being less than two millimetres high. This shouldn't bother younger readers or those with good eyesight, but if you struggle with this it's something to bear in mind.

★★★★☆



"Everything from human emotion to nuclear fission is explored and explained through graphics and text"

YOU MAY ALSO LIKE…

Information Is Beautiful
Author: **David McCandless**
Publisher: **Harper Collins**
Price: **£24.99 (approx. $30)**
Release date: **Out now**

It's a few years old now, but this truly is a book for those who love information presented simply. Most pages have less than 40 words on them, but this is still a beautiful book to flick through.

Infographics: Space
Author: **Simon Rogers and Jennifer Daniel**
Publisher: **Big Picture Press**
Price: **£12.99 / $17.99**
Release date: **Out now**

This book mainly focuses on explaining space to younger readers, and features beautiful graphics that draw the eye and incorporate text into the images. Great for those who love science.

Science But Not As We Know It
Author: **Ben Gilliland**
Publisher: **DK**
Price: **£9.99 (approx. $12)**
Release date: **Out now**

Reaching more into the textbook area than the other books on this page, Gilliland lays out information in a very neat and informative way and explains complex ideas in simple language.

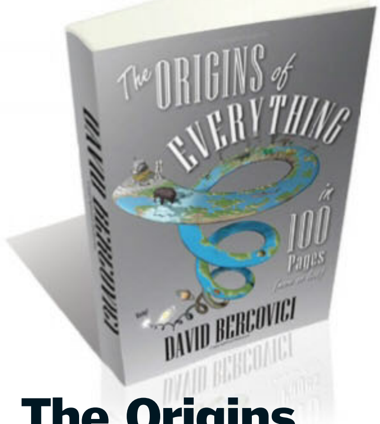
It Can't be True! 2

All the facts you'll ever need in a visually stunning release

- Author: **Various**
- Publisher: **DK**
- Price: **£12.99 / $19.99**
- Release date: **Out now**

Much like **HIW**, this fantastic book is the polar opposite of a boring old school textbook. *It Can't Be True! 2* has the winning formula of amazing facts and vivid imagery in abundance, and there's something for everyone, young and old, in this release.

Every page contains diagrams and infographics based on the natural world, the Solar System and feats of human engineering. Amazing facts from the unbelievable to the quirky are interspersed throughout. Did you know one lightning bolt could toast 10,000 slices of bread, and a hippopotamus can fit a Ferrari in its mouth? The relentless amount of eye-boggling facts make this an excellent read that you will keep returning to again to feed your mind.



The Origins Of Everything In 100 Pages (More Or Less)

13.8 billion years of history in one book

- Author: **David Bercovici**
- Publisher: **Yale University Press**
- Price: **£12.99 / $23**
- Release date: **Out now**

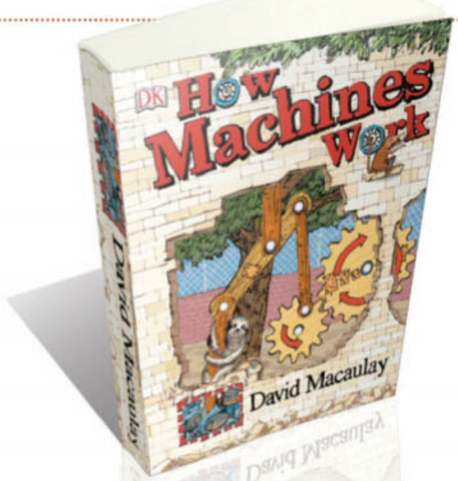
Written by geophysicist David Bercovici, *The Origins Of Everything In 100 Pages* is a sort of greatest hits package of the history of the universe. From the Big Bang to the dawn of humanity, it covers a lot of scientific ground. The text is trimmed of fat but this can water down the experience, leaving the reader wanting more.

That said, the book is filled with facts and is an ideal starting point for anyone wanting to know more about the history of the universe. It also includes a telling final page on the future of the Earth and the challenges that lay ahead for humanity.

How Machines Work: Zoo Break!

Fun, hands-on physics

- Author: **David Macaulay**
- Publisher: **DK**
- Price: **£14.99 / $19.99**
- Release date: **Out now**



How Machines Work: Zoo Break! is the perfect way to introduce youngsters to basic physics. The mechanics of simple machines are tackled in this fun book, which is primarily aimed at a younger audience. The theme is based around the contraptions a sloth and a shrew have constructed to try and escape from a zoo.

The narrative is a nice touch, but it's the colourful pullouts and flaps on every page that explain how the machines work that is the best part of the book. Similar to Macaulay's previous release *The Way Things Work*, there's no better way to make the occasionally tedious parts of physics that bit more exciting.

How Do Worms Work?

A collection of gardening curiosities explained

- Author: **Guy Barter**
- Publisher: **Mitchell Beazley**
- Price: **£14.99 (approx. $19)**
- Release date: **Out now**

This title from the Royal Horticultural Society is the perfect choice for any budding (pardon the pun) gardening enthusiasts, but will also appeal to anyone interested in wildlife. *How Do Worms Work?* is presented as a series of questions and answers, complemented by illustrations and photographs. While many questions are clearly aimed specifically at gardeners, with handy horticultural tips dotted throughout the book, a lot of the information will engage naturalists too. If you've ever wondered why flowers close at night, or how seeds know which way is up, then this is the book for you.

Spaceman

Find out what it takes to become an astronaut

- Author: **Mike Massimino**
- Publisher: **Simon & Schuster**
- Price: **£20 / $28**
- Release date: **Out now**

Veteran NASA astronaut Mike Massimino knows a thing or two about space travel. He was mission specialist in two high stakes Hubble servicing missions, and conducted spacewalks to fix the multi-billion dollar telescope's flawed mirror. In this book he explains what drove him to pursue a career as an astronaut (despite being rejected by NASA three times) and describes his various missions and what it feels like to leave Earth. With his immersive narrative, you feel as though you are actually there with him waiting for launch.

Science: A History In 100 Experiments

How the most important discoveries were made

- Author: **John and Mary Gribbin**
- Publisher: **William Collins**
- Price: **£25 (approx. $30)**
- Release date: **Out now**

The latest title from established science writers John and Mary Gribbin charts the history of some of the greatest scientific achievements. From Archimedes' experiments with displacement in the 3rd century BCE, to the recent discovery of gravitational waves, each breakthrough is covered succinctly in under three pages, together with diagrams and photography where relevant. The tone is well-balanced, providing the experiments with context, while the science itself is made easy to understand without being patronising. While this title is better suited to dipping in and out of rather than reading cover to cover, it provides a brilliant insight into the scientific method.

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How to make a stalactite

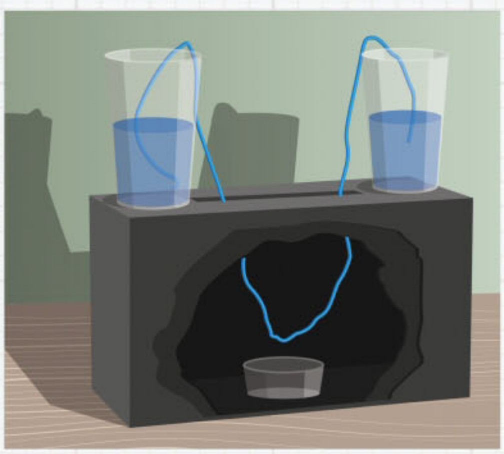
Find out how these amazing rock structures can be made using science at home

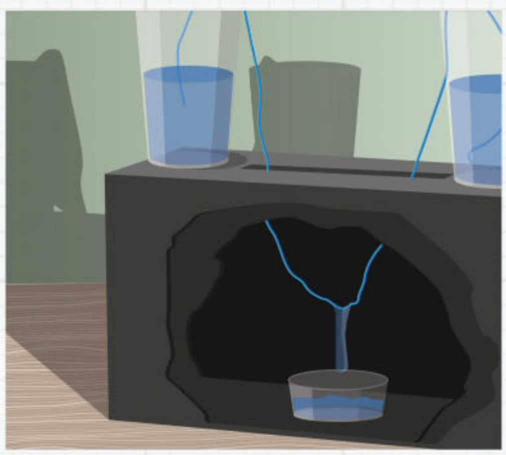
DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU

1 Prepare your 'cave'
You can use an old shoebox as your 'cave' for the stalactite to form in. Remove the lid from it and stand it on its side, then cut a small, letterbox-style hole in the top – this is where your stalactite will hang. If you like, you can paint the inside of the box grey, and even cut out a cave shape from the lid and slide it inside if you want it to look more realistic.

2 Mix your solution
To make your solution, you'll need a white mineral powder called magnesium sulphate, which is commonly called Epsom salt. A lot of chemists stock this, so ask an adult to help you find some. Mix some blue food colouring in a jug of warm water, then slowly add the Epsom salt, stirring it until no more salt will dissolve. Then split this solution into two glasses.

3 Make a bowl
Find a plastic cup and cut most of the top off to make a shallow bowl. When the water solution drips down to form the stalactite, the salt will stick to the stalactite and make it longer, but some of the water will drip down. Your box is only made of cardboard, so you need to make sure you catch the drips. To do this place your bowl in the centre of your cave's base.





4 String it up
Cut a 40-centimetre piece of string and put the whole length of it into one of the cups. It needs to soak up some of the water so that it's wet when you start – then the water will start dripping down to the middle of it. Next, put around ten centimetres of the string into each of the two glasses, so it hangs between them and dangles into the slot you cut from the top of the box.

5 Watch it drip
You'll need to leave your cave set up for around a week to see the results – the longer the better. As the water is soaked up by the string the solution will drip down to the centre of the string and the salt will form into a pillar, called a stalactite. As more water drips down, more salt will stick to the stalactite and it will gradually get longer and longer.

"The salt will stick to the stalactite and make it longer"

In summary…
When the Epsom salt dissolves in the water it breaks down into tiny particles called ions. The solution then drips down and the ions in the water are attracted to each other, to form crystals. The water will then drip away, but the crystal will keep getting bigger.

How to make a jungle

Create a jungle in a bottle and see how ecosystems work

NEXT ISSUE

BUILD A BAROMETER

MAKE YOUR OWN AIR FRESHENER

1 Create a base

First, cut a two-litre bottle into two pieces, so the base is around ten centimetres high – keep the top for later. Pour a layer of small stones into the bottom of the base, then add a layer of crushed charcoal. Top this off with a layer of pistachio nut shells. In a moment, you'll be adding a plant on top, and these thick layers will let water drip through and form a small pool at the bottom.

2 Add your plant

Take a small potted plant and place it carefully on top of the pistachio shells, but try not to shake up the bottom layers. Then add some more soil from the plant pot and pat it down gently. The charcoal in the bottom is absorbent, so it should soak up some of the dripping water. It will also soak up the chemicals that any dead plants create so your jungle won't get too smelly.

3 Water and seal

Spray your plant with water, and also pour a little water into the soil to make sure it's damp. Now your jungle is ready to be sealed off. Place the top half of the bottle over the top of the plant and then seal it tightly with sticky tape around the base. Screw on the top of the bottle tightly to stop air getting in, and store it somewhere warm and light, but not in direct sunlight.

"Your jungle is now ready to be sealed off"

In summary…

The plant absorbs the water from the soil, then it passes through the plant and out through tiny holes in the leaves as invisible water vapour. This vapour condenses on the bottle, drips down into the soil, and the process starts again. This is just like rain falling in the jungle.

WIN!

A voice-controlled quadcopter drone

The X-Voice quadcopter comes with a microphone and earpiece so you can direct the drone with voice commands

How did Einsten describe quantum entanglement?

"_______ action at a distance"

Pick the missing word:

a) **Squeaky**

b) **Sleepy**

c) **Spooky**

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Letter of the Month
Weird wheel motion

Dear **HIW**,
Watching TV, I noticed how a car's wheels seem to turn backwards. I understand the reason it looks this way is because the camera doesn't have a high enough frame rate to capture a full rotation. I was wondering, do our eyes have a frame rate, or are they effectively perfect at capturing images? If they are, why is it so difficult to make a camera with a higher frame rate?
Patrick Kyle

The frame rate of standard TV cameras can't keep up with how quickly the wheel is turning, so to us it appears as though it is moving anti-clockwise. Strobe lighting works in a similar way, as the flickering light presents snapshots of an image that don't fully capture its movement.

Human eyes don't work like a camera, but if we were to measure them in frames per second, it would be around 75 FPS. This is because it takes us about 13 milliseconds to process an image. Other animals, particularly smaller rodents and birds, may see at a much higher frame rate.

There are some cameras that are capable of incredibly high speeds – some have frame rates in the millions, billions or even trillions! These can be used in laboratories to capture rapid chemical reactions, but they don't operate in the same way as typical TV camera devices.


The camera does not fully capture the wheel's rotation so it looks as if it is going backwards

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Explosive decompression

Dear **HIW**,
I was thinking, if you opened the door of a plane in mid-air when the cabin was pressurised, would you get sucked out or pushed out because of the high-pressure air in the cabin flowing out into the low-pressure air?
Henry Jackson

First and foremost, the inward opening doors found on most commercial planes can't be opened during flight. The pressure on the door at high altitude forces it shut with a strength that even the most muscle-bound human couldn't move. If it could be opened, the decompression would make all the air rush out, sucking everything out with it. There would also be a very rapid loss of oxygen and a fall to sub-zero temperatures.

Oxygen masks can be issued as an aircraft descends to lower altitude, and smaller planes – like those used for parachuting – are unpressurised so the doors can open.


Sudden decompression can be fatal, but it's not as explosive as it's often portrayed in action and disaster films

Why the croaky voice?

Dear **HIW**,
I love your magazines and I'm always excited when I get them through the door. I was wondering, why does our voice go croaky when we have a sore throat?
Jessica

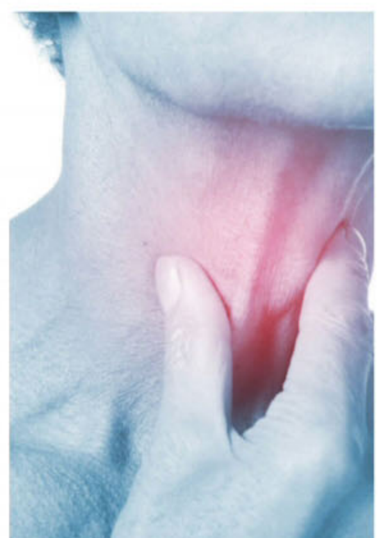
To enable us to speak, our vocal cords vibrate as air is pushed from the lungs to the mouth. These vibrations are then changed into sounds by our mouth, throat and nose. When you have a sore throat your vocal folds swell due to a respiratory tract infection. The inflamed membranes no longer vibrate in the same way, making your voice sound croaky.


Jellyfish are about 95 per cent water and have no bones

Jellyfish don't have brains

Dear **HIW**,
I love your magazine and I am a new subscriber, but my question is: how do jellyfish live without a brain?
Harry Pearce

Jellyfish may not have a brain but they do instead have various mechanisms that help them survive. Nerves are located at the base of the tentacles and have the ability to detect temperature, light and salinity. Without a brain, jellyfish are completely reliant on these reflexes. Movement and catching prey is all down to chance. They use ocean currents to drift, and simply wait for prey to touch a tentacle before they strike. Oxygen is absorbed through the skin, and they have no blood, so there's no need for a heart or a pair of lungs either!


The majority of sore throats are caused by viral infections, but they can also be caused by bacteria

HOW IT WORKS

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SpaceX, NASA, Mars One - who will reach the Red Planet first?

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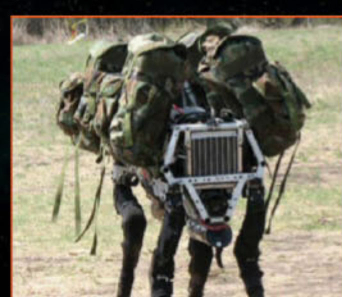
- Inside NASA's Space Launch System
- How the first Space Race got us to the Moon
- Elon Musk's Mars ambitions

How stress affects your mind and body



War robots: military machines revealed

Discover amazing caves of the world

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FAST FACTS

Amazing trivia to blow your mind

25% OF ALL MARINE LIFE LIVES IN CORAL REEFS

185 THE TOTAL NUMBER OF YEARS DEMOCRACY LASTED IN ANCIENT ATHENS

TWO MILLION
THE NUMBER OF WORKING PARTS IN THE HUMAN EYE

687 DAYS
THE LENGTH OF A YEAR ON MARS

OVER 99.9%
THE PROPORTION OF AN ATOM THAT IS EMPTY SPACE

110KM/S
THE SPEED AT WHICH THE ANDROMEDA GALAXY IS APPROACHING THE MILKY WAY

CHERNOBYL'S RADIOACTIVE RAIN SPREAD AS FAR WEST AS IRELAND

1.8KG
THE WEIGHT OF ALL THE BACTERIA IN THE AVERAGE HUMAN BODY

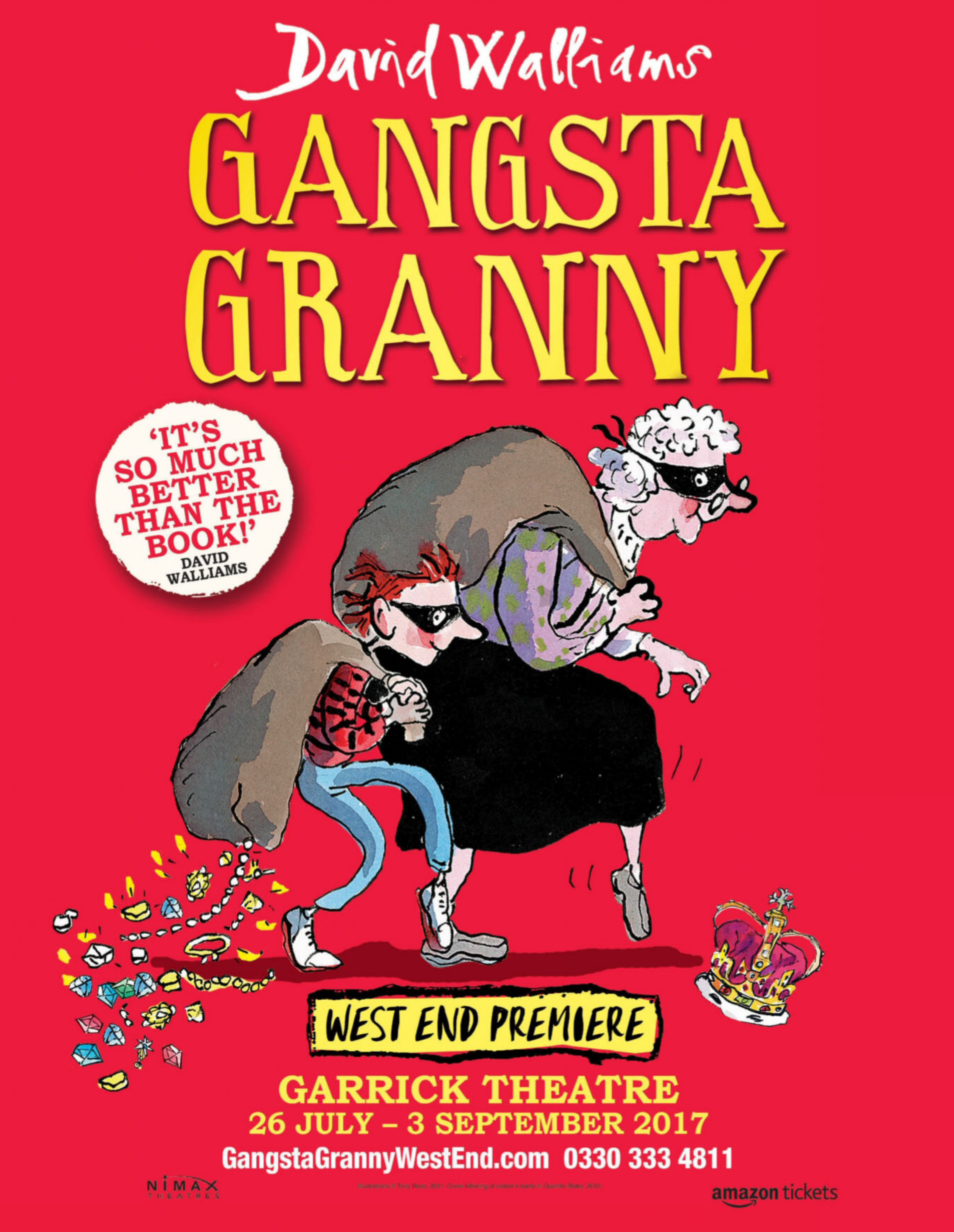
25,000KM THE MAXIMUM LENGTH OF HUMPBACK WHALE MIGRATION PATHS

THE MALLEEFOWL BIRD TAKES THE TEMPERATURE OF ITS NEST USING ITS TONGUE

1.7%
AMOUNT OF THE WORLD'S TOTAL WATER THAT IS HELD IN GLACIERS, ICE CAPS AND PERMANENT SNOW

~300
THE NUMBER OF BONES A BABY HAS. THIS REDUCES TO 206 AS THEY GROW

54.5% THE PROPORTION OF THE HUMAN POPULATION LIVING IN URBAN AREAS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